MÁRIO JOÃO SILVA BENEVIDES

AUTOMATED SORTATION SYSTEMS

CROSS BELT TECHNOLOGY

UNIVERSIDADE DO ALGARVE

INSTITUTO SUPERIOR DE ENGENHARIA

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Mestrado em Engenharia Elétrica e Eletrónica

Trabalho efetuado sob orientação de:

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UNIVERSIDADE DO ALGARVE

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Declaração de autoria de trabalho

Declaro ser o autor deste trabalho, que é original e inédito. Autores e trabalhos consultados estão devidamente citados no texto e constam da listagem de referências incluída.

Mário João Silva Benevides

(Mário João Silva Benevides)

RESUMO

Durante a minha atividade profissional sempre me dediquei a melhorar o meu conhecimento em diversas áreas da engenharia através de formações e cursos, dos quais destaco principalmente a Licenciatura em Engenharia Elétrica e Eletrónica, no ramo de Sistemas de Energia e Controlo. Para além das minhas competências técnicas, sempre mostrei interesse em melhorar as minhas capacidades interpessoais, como liderança, a qual me levou a fazer parte do grupo local BEST (*Board of European Students of Technology*) na Universidade do Algarve, durante o meu percurso académico.

Durante o meu percurso profissional, inicialmente desempenhei funções na Itelmatis (Faro, Portugal) na área de comissionamento de sistemas de automação e na gestão de contratos de manutenção na mesma área de negócio. Posteriormente, trabalhei na General Motors (Gliwice, Polónia) na prestação de serviços aduaneiros para equipamentos eletrónicos utilizados em automóveis e equipamentos necessários para auxilio de testes em automóveis. Desde novembro de 2014 exerço funções de engenheiro de comissionamento na Vanderlande, em sistemas de automação para processamento de materiais, mais concretamente na tecnologia tipo *Cross belt.* Para além das funções diretas de comissionamento, presto suporte técnico a clientes e coordeno testes de integração em obra entre diferentes subsistemas.

A Vanderlade é uma empresa líder de mercado no fornecimento de soluções de manuseamento de materiais para as áreas de logística, armazenagem de materiais e aeroportos. A Vanderlande possui sede nos Países Baixos e conta com mais de 3500 colaboradores distribuídos em diversos pontos do globo com funções de engenharia e suporte global.

Uma das diversas soluções que a Vanderlande possui no seu portefólio é o *Cross belt sorter* ou *Loop sorter*. É um sistema transportador que permite classificar diversos tipos de artigos, sendo desenvolvido para as áreas de logística e armazenamento de materiais.

Por definição um *Cross belt sorter* é um sistema de transporte automatizado utilizado na classificação de artigos constituído por membros chassi com rodas ligados entre si formando um laço. Na parte superior dos chassis, existem tabuleiros independentes compostos por uma tela que se movimenta na direção perpendicular ao movimento do transportador principal.

O *Cross belt sorter* tem como características principais ter capacidade para processar um elevado número de artigos num curto espaço de tempo e uma alta flexibilidade em classificar

uma grande variedade de artigos, como por exemplo: sacos de plástico, cartões, bolsas, embrulhos, envelopes e artigos de retalho.

Este tipo de sistema de transporte de classificação de artigos utiliza diversos tipos de tecnologias e subsistemas de forma a desempenhar a sua função. Para além do transportador principal, o *Loop sorter* é constituído normalmente, dependendo das especificações de cada projeto, por uma pluralidade de transportadores de tela e/ou rolos, por scanners leitores de código de barras, medidores de volume e balanças dinâmicas que efetuam a pesagem de cada artigo. Relativamente à parte de controlo existe normalmente um controlador principal podendo ser um computador industrial ou um autómato que comunica com os diferentes escravos do sistema. Os escravos podem ser simples módulos de I/O que recebem sinais digitais de 24Vdc para controlo e leitura de sensores, motores e *encoders* para medição de velocidade, ou podem ser controladores embebidos com funções mais avançadas, como é o caso dos controladores de barreiras de leds, que detetam o formato de cada artigo através do cálculo da combinação da velocidade do transportador em questão e o bloqueio simultâneo de leds. Na parte de comunicações existe uma rede principal de comunicações (por exemplo PROFINET), que possibilita a comunicação entre o controlador principal e os diferentes escravos incluindo *gateways* de comunicação, que têm como finalidade fazer a conversão do protocolo de comunicações da rede principal para uma rede secundária, como é o caso de AS-Interface *gateway*, que faz a conversão de PROFINET para AS-I e vice versa.

Em relação ao processo de classificação de artigos, embora existam uma variedade de fatores, este depende principalmente do servidor de destinos e das regras de classificação programadas. Seguidamente, descreve-se de forma resumida, o percurso de um artigo para ser classificado no seu destino final:

- Inicialmente cada artigo é colocado manualmente nas linhas de alimentação do *Cross belt sorter* por operadores do sistema ou transportado por linhas de transporte até às linhas de alimentação;
- Nas linhas de alimentação o peso de cada artigo e dimensões são verificados. Caso seja detetado que o artigo se encontra fora do padrão, é gerado um erro no sistema de forma a que os operadores do sistema possam remover o artigo com segurança;
- Após as dimensões serem calculadas e o artigo ser detetado como válido, posteriormente este será transportado até ao transportador principal, o *Loop sorter*, sendo imperativo uma sincronização entre a linha de alimentação em questão e o *sorter*;

- Seguidamente no transportador principal o volume e código de barras são lidos, sendo esta informação transmitida para o servidor de destinos para atribuir destino;
- Após o artigo possuir destino, o controlador do *Loop sorter* vai tentar classificar o artigo. Caso não seja possível, o artigo continua a circular, fazendo novamente uma leitura e um pedido de destino de forma ter uma próxima tentativa de classificação;
- Finalizado o processo, são enviados relatórios a confirmar o sucesso da classificação do artigo.

Relativamente à parte prática e à metodologia de projeto utilizada para a realização de projetos de comissionamento da tecnologia tipo *Cross belt*, devido à rigidez e estrutura sólida das diferentes fases do projeto, com prazos de entrega bem definidos e elementos a fornecer para as fases posteriores pré-especificados, utiliza-se a metodologia do tipo *Waterfall*. Esta metodologia está estruturada da seguinte forma: requisitos; análise; desenho/engenharia; implementação em obra; teste e validação; validação do cliente; suporte e encerramento do projeto.

Os requisitos do sistema é onde o projeto se inicia com todas as especificações descritas e explicadas de forma clara. Na fase de análise os requisitos são analisados de forma critica de forma a planificar as seguintes fases de projeto. Desenho/engenharia refere-se na elaboração do programa de configuração que será utilizado no sistema de *Cross belt* em questão, sendo também elaborada documentação de interface, definindo como os diferentes sub-sistemas devem comunicar entre si. A fase de implementação é a mais extensa do projeto onde ocorre o comissionamento do sistema, existindo também pequenas provas de validação antes das provas finais. Na fase de teste e validação todos os requisitos do sistemas são testados de forma a verificar a conformidade do projeto. Na fase de validação do cliente é feito uma vez mais uma validação completa do sistema pelo cliente, inclusivamente componentes elétricos e mecânicos, para além das funcionalidades pretendidas. Segue-se a fase de suporte ao cliente, na qual durante as primeiras semanas o sistema encontra-se em funcionamento, utilizando-se também este período para formação do cliente. Após todas as fases anteriores concluídas encerra-se o projeto com *backups* de configuração, notas de retificação de projeto durante a sua realização, finalizando-se com uma análise critica de pontos a melhorar para o próximo projeto.

Palavras Chave: Cross belt sorter, Loop sorter, Sistema de triagem, Sistema transportador, Automação.

ABSTRACT

Vanderlande is a material handling and logistics automation company based in the Netherlands and operates worldwide. Is a market leader in the supply of solutions for process automation at airports, parcel market and for warehouse.

An automated conveyor system is generally composed by one or different types of electromechanical components, controlled by a main controller device and is used to transport materials or goods from one point to another. The automated conveyor technology brings a variety of benefits to multiple industries, such as, safer material handling and making processes more efficient and reliable.

A *Cross belt sorter* or *Loop sorter* is an automated conveyor system designed for parcel and postal, and warehousing markets in order to help processing stored goods and shipping parcels. Compared to other automated systems, the *Loop sorter* is mainly characterized to be able to process high volume items and sort a wide range of products, such as, plastic bags, cartoons, totes, parcels, envelopes, and clothes.

As a commissioning engineer at Vanderlande I had the opportunity to participate in different projects involving a *Cross belt sorter*. Hereby, this report describes the activities that I was involved regarding the *Loop sorter* resuming the required steps to make a system fully functional, but also explaining the technology involved, including hardware components, communication protocols and controllers.

Keywords: Cross belt sorter, Loop sorter, Sorting system, Conveyor system, Automation

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LIST OF ABBREVIATIONS

AS-I	AS-Interface
CAN	Controller Area Network
CRC	Cyclic-Redundant Checksum
CPU	Central Processing Unit
DOL	Direct On Line motor starter
DS	Destination Server host
FSC	Flow System Controller;
GUI	Graphic User Interface
HMI	Human Machine Interface
HLC	High Level Controls
IP	In most often cases refers to Internet Protocol, and it means Industrial Protocol when associated with EtherNet/IP
IEEE	Institute of Electrical and Electronics Engineers
I/O	Input/Ouput
IRT	Isochronous Real-Time
LAN	Local area network
LLC	Low Level Controls
MAN	Metropolitan Area Network
OSI	Open Systems Interconnection
PLC	Programmable Logic Controller
PNDP	PROFINET-PROFIBUS coupler
PNPN	PROFINET-PROFINET coupler
RT	Real-Time
SCADA	Supervisory Control And Data Acquisition
TCP	Transmission Control Protocol
WAN	Wide Area Networks

1. INTRODUCTION

1.1. Framework

The Professional Activity Report has the goal to summarize the working experience of an Electric and Electronic Engineer which performs its professional activity in the engineering area and it goes in accordance with RT.033/2011 regulation. The mentioned regulation allows the university graduates to obtain ETCs though the execution of a Professional Engineering Activity Report.

During my professional activity I had the privilege to execute complex projects in the automation area, located on different geographic places all over the world. Projects covered the conveyor systems technology with solutions for the following business areas: logistic centres, warehousing, e-commerce, postal and airports. My professional activity was focused mainly on the *Cross belt sorter technology* conveyor system.

Hereby, the activities that I developed included engineering support during project preparation, reviewing requirements and functionalities; engineering of the software configuration program before site deployment; definition and execution of interface specifications documentation for controllers and other systems that the *Cross belt sorter* interfaces; system commissioning on site; customer support on site during the first weeks when the system is live and system operational training for machine operators.

The level of complexity of this type of projects allowed me to develop competences in the following areas of automation: electric, mechanic, software and communication protocols. Beyond the professional competences I enriched myself culturally due to be most of the time being moved geographically and in leadership in due to the coordination of some project site works.

1.2. Report goals

As goals of this report I have the objective to study and analyze the different technologies involving the *Cross belt sorter*, such as communication protocols, controller types and different hardware components. I aim to clarify the different working principles of this conveyor solution and different sortation mechanisms.

In the practical content of the report I will make reference to all project activities that I was involved as commissioning engineer for *Cross belt sorters* making reference to a project methodology to structurally explain how I proceed during the different phases of the project. I also make reference to practical existing scenarios explaining how to commission a *Cross belt sorter*, test it and integrate with other subsystems.

The content of this report it has mainly reference to the *Cross belt sorter* used by the company Vanderlande.

1.3. Report structure

The report is structured in six chapters. At first I describe detailed the company where I practice engineering functions and I describe my professional path since I finalized the university degree in Electric and Electronic Engineering with specialization in control and power systems.

On a second phase I describe the state of the art of the *Cross belt sorter* technology, including the different system elements and components, and how they interface with each other.

On a third phase I describe my working activity related to the *Cross belt technology*, more precisely the commissioning steps of a *Cross belt* system and points to be considered.

At last, the report is finalized with a conclusion of the *Cross belt technology* with a general review and few points that I consider to be improved.

It is important to refer that the current report focuses on projects developed within the company Vanderlande.

2. PROFESSIONAL ACTIVITY

During my professional activity I always aimed to improve my knowledge on different engineering field’s trough training sessions such as Siemens Simatic PLC programming and other Siemens equipment’s training, also safety training for construction sites and the presence in academic courses in the BSc. of Electric and Electronic degree with specialization in energy and control systems. Apart from my hard skills and professional competences I was always interested in the soft skills competences, such as leadership skills which led me to enroll in the local group of Board of European Students of Technology (BEST) in the University of Algarve.

Hereby, bellow I describe my professional path and executed functions:

2.1. 2009-2012. Board of European Students of Technology (BEST) Faro Algarve

In 2009 together with other University of Algarve colleagues we founded the local group of Board of European Students of Technology (BEST) Faro Algarve. From that date I developed functions related with project management, by organizing and managing different career and academic events, such as, summer courses and engineering weeks. I also developed functions in the sales area, contacting and creating partnerships for the different events and functions in the marketing area for the promotion of events.

In 2011 I was elected as president of the local group board, where I managed and lead the local group for a year. I was in daily contact with different partners, including university members, engineering companies and national institutes. I was also present in multiple international seminars for training skills (leadership, project management, sales and marketing), and international BEST growth related subjects.

2.2. 2013-2014. Itelmatis in Faro, Portugal

In 2013 I started my first professional experience in the engineering field in Itelmatis. I developed multiple functions, from commissioning and maintenance engineer to customer maintenance contract manager. Itelmatis focuses in tailor made automated products and solutions for greenhouses, irrigation systems, water pumping stations and building management systems. As commissioning engineer I had the opportunity to commission Itelmatis automated solutions. As customer maintenance contract manager I had to plan and schedule maintenance activities, I defined and readjusted maintenance plans according to each installation needs, I provided consulting services after each maintenance activity for eventual system improvements.

As maintenance responsible person I also carried occasionally preventive and corrective maintenance activities on different customer systems.

2.3. 2014 (July to October). General Motors in Gliwice, Poland

In July of 2014 I started working in automobile industry in General Motors in Poland as customs analyst for electric and control components to be incorporated in vehicles or used during the vehicles tests. I had to classify the different components according to each item category when being supplied from one country to another.

2.4. From 2014 (on going). Vanderlande in Veghel, Nederlands

In November of 2014 I joined Vanderlande as commissioning engineer for the *Cross belt sorter* systems. I'm responsible to commission *Cross belt* sorters according to each system specifications, programming all low level components part of the *Loop sorter*. When in the office I give support during engineering phase for *Loop sorters* and prepare the following projects. On site, apart from the commissioning I cooperate and coordinate integration tests with internal and external Vanderlande partners (barcode and volume scanners, weighing scales, destination servers, SCADA and PLC).

Beyond my commissioning and engineering functions I give machine operational training to customers and occasionally I do standby support in case customers are in the need of technical assistance to solve incidents in their system.

3. PRESENTATION OF VANDERLANDE ORGANIZATION

Vanderlande is a material handling and logistics automation company based in Veghel, Netherlands.

The company was established in 1949 by Eddie van der Lande, initially producing machines for textile industry, hoisting apparatus, cranes and conveyor belts for oil barrels and large materials. In 1963 Vanderlande made a partnership with the American company Rapiscan Incorporated and started developing and delivering customized transport systems globally. In 1988 NPN Capital acquired majority of the company's shares where it kept growing in the automation area of material handling systems and logistics. In 2017 the company was acquired by Toyota Industries Corporation (TICO) creating a synergy and consequently the opportunity to development and build new products and solutions.

Today, Vanderlande is a world market leader in the supply of solutions for process automation at airports, parcel market and for warehouses.

As facts and numbers, Vanderlande baggage handling systems are present in more than 600 airports, moving more than 3.7 billion pieces of luggage per year. Also, more than 39 million parcels are being sorted everyday by Vanderlande systems.

Apart from its headquarters in Veghel and other production and service centers in Netherlands, Vanderlande is present in Argentina, Belgium, Brazil, Germany, France, Spain, United Kingdom, Canada, China, India, South Africa and United States. Today Vanderlande counts with more than 5500 employees worldwide.

VANDERLANDE

Figure 3-1 Vanderlande company logo.

4. STATE OF THE ART – CROSS BELT SORTER TECHNOLOGY

4.1. Introduction – Automated conveyor systems

Automated conveyor systems are generally composed by one or different types of electromechanical components, controlled by a main controller device and are used to transport materials or goods from one point to another.

Conveyors have a wide variety of applications on different industries, and can be commonly within material handling systems, packing industry and airports, making product transportation an automated solution.

Figure 4-1 Vanderlande *TRUXORTER* solution.

Automated conveyor systems bring a variety of benefits to different industries:

- Safer material handling, especially regarding heavy loads and items with considerable volume;
- Being an automated solution it makes the processes more efficient and reliable, with less human mistakes;
- Higher capacity systems;
- Less finger prints on products, making the material handling more secure, especially on airports;
- Better use of space, for instance, by implementing conveyor solution on different heights.

Within the conveyor systems there is a big variety of automated technology solutions dedicated to different industries and the *Cross belt* technology is one of them.

4.2. System overview

A *Cross belt sorter* or *Loop sorter* is an automated conveyor system comprising a plurality of wheeled chassis members linked together to form an endless loop on top of a track. On the chassis, carriers are assembled where objects can be placed and discharged (sorted) in the transversal direction of the movement of the *Loop sorter*.

Figure 4-2 Vanderlande *Cross belt sorter* - SCS1200.

<u>Industry Applications:</u>

The *Cross belt sorter* type can be used on a wide range of industries: distribution centres, parcel and postal, clothing and apparel, food and beverages, general merchandise and e-commerce.

Advantages and Features:

- High capacity systems;
- Better use of space due to its high flexible layout, with multiple combinations possible, between curves, inclines, declines and different setup possibilities for feeding and discharge lines;
- High product range, a single system being able to sort simultaneously heavy and light items, with different dimensions and shapes such as bags, cartoons, totes, parcels, envelopes, clothes, beyond others;
- Generally easy to maintain and to replace parts;
- Low noise and lower power consumption on a quite variety solutions on the market due to the *Loop sorter* being driven by Linear Synchronous motors;
- High accuracy on inducting and sorting;
- Easy to expand input and output lines.

4.2.1. System functional behaviour:

4.2.1.1. General system operation design rules:

On the *Cross belt sorter* systems, the main goal is to sort accurately the maximum amount of items on the shortest period of time. This type of system is designed to reach the maximum capacity possible. In order to achieve that, items should not recirculate, meaning that after an item being inducted and screened the sortation should take place on the closest sortation zone. If there are items already allocated on the sorter and have to pass through a merge zone, the related induction lines will lose capacity due to less allocation windows being available.

Thus, in general the destination host server doesn't set an output destination to an item to cross over another merge zone after receiving a valid screen result. An item recirculates most of the times due to external faults, such as, damaged labels not being possible to be read at first on the screening positions or due to the designated destination being temporarily unavailable or full with other items. Another reason which justifies item recirculation happens on the systems that have poor destinations management. It happens mostly when there is more than one merge zone and the items loaded on the induction lines can have different valid destinations for an only single valid physical destination. On this case it is not possible to predict and avoid recirculations,

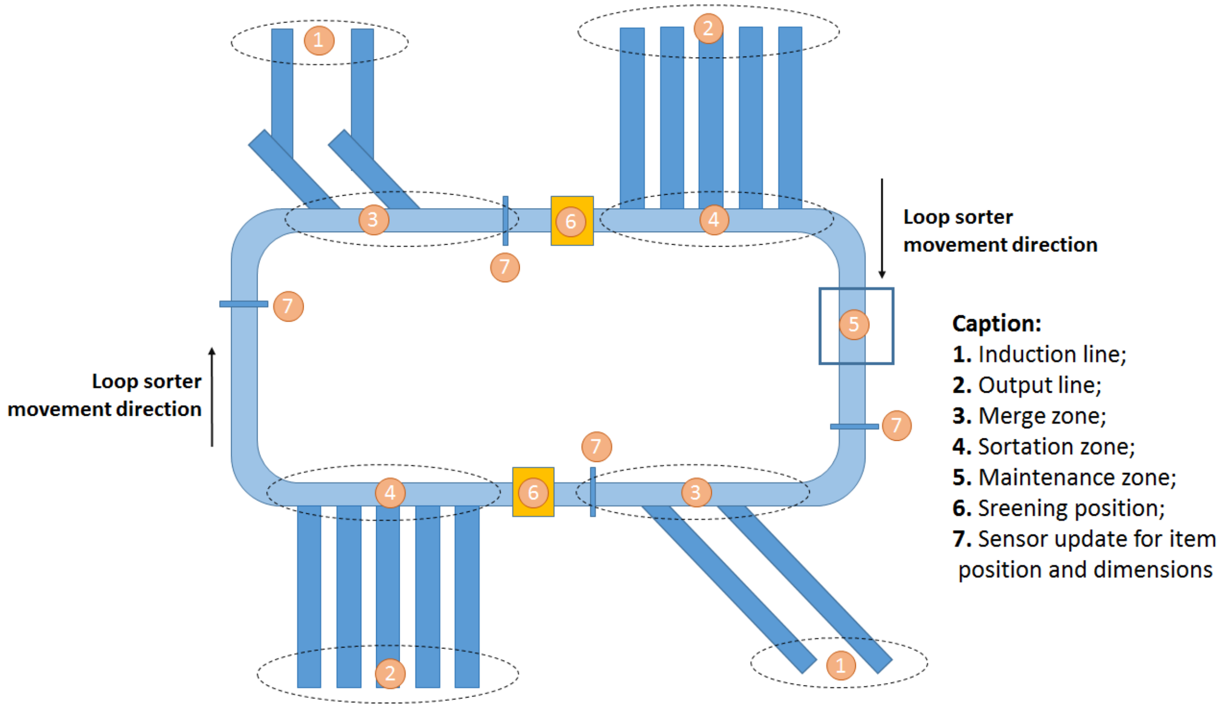


Figure 4-3 Example of a *Cross belt sorter* layout.

4.2.1.2.Item flow diagram and sortation principle:

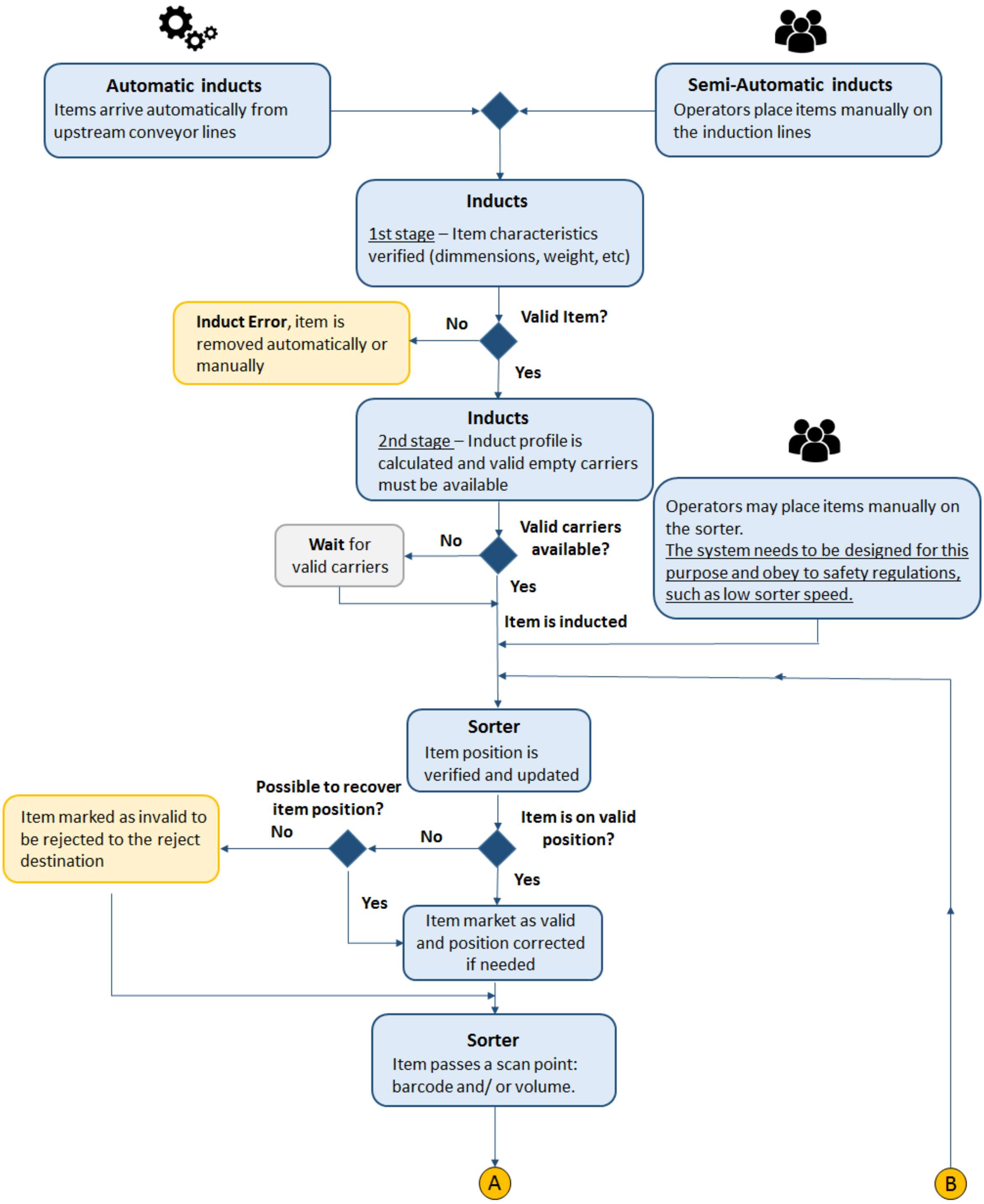
On the figure 4-3 it is represented an example of *Cross belt sorter* system layout and on figure 4-4 it is represented an example of an item flow diagram. Below is explained the sortation principle and the item flow diagram:

- Items are loaded on the induction lines (1) manually or delivered automatically by other upstream conveying system;
- On the induction lines before an item being inducted two preconditions need to be fulfilled: At first, items are verified for its characteristics (weight, dimensions, etc). If an item doesn't respect system programed conditions an system error occurs, so that the related item can be removed manually or automatically; At second stage, when an item dimensions (length and width) is determined the system looks for the first available carrier which can take the item;
- After an item being inducted (3), its position and length is updated and verified at the next update position (7). On most of the systems it's used a photocell sensor for this purpose, but for specific low item applications (example: envelopes), advanced cameras systems are used;

  At this position, after the item being verified, a small item correction may happen on the transversal direction of the movement of the sorter. If it is not possible to correct the item position, it may be marked as invalid, to be discharged to a reject destination, since incorrect positioned items on the *Cross belt sorter* can be armful for the system;
- At the scan point position (6) each item is screened for barcode and/ or volume;
- After the screening position, the *Cross belt sorter* controller sends a request message with the result of the screening per each single item to the destination host server. Based on the item data and internal sorting rules the destination host server replies with a valid destination to the *Cross belt sorter* controller. If the screening result is not valid, the destination host server normally sends a message to the *Cross belt sorter* to recirculate the related item, so it can be rescreened. After an item reaches a predefined number of screen failures or recirculation's on the sorter, the destination host server sets this item to a no read destination where the machine operators can evaluate state of label and the item;
- After receiving destination(s), an item should be ready to sort at (4). The sorting action happens only if the assigned destination(s) are available. If an item loses the first

opportunity to be sorted, it can still try to sort to an alternative destination if it was assigned by the destination host server, otherwise the item will recirculate;

- After the sortation taking place, the carrier which the item was placed, is verified on the item verification position (7). If the item is not present anymore on the *cross belt*, a successful sort report message will be sent to the destination host server. By opposite, if the item remains on the system, a fail sort report will be sent to the host and the item will recirculate.


Automatic inducts
Items arrive automatically from upstream conveyor lines
Semi-Automatic inducts
Operators place items manually on the induction lines
Inducts
1st stage – Item characteristics verified (dimmensions, weight, etc)
Valid Item?
No
Yes
Induct Error, item is removed automatically or manually
Inducts
2nd stage – Induct profile is calculated and valid empty carriers must be available
Operators may place items manually on the sorter.
The system needs to be designed for this purpose and obey to safety regulations, such as low sorter speed.
Valid carriers available?
No
Yes
Wait for valid carriers
Item is inducted
Sorter
Item position is verified and updated
Possible to recover item position?
No
Item is on valid position?
No
Yes
Yes
Item marked as invalid to be rejected to the reject destination
Item market as valid and position corrected if needed
Sorter
Item passes a scan point: barcode and/ or volume.
A
B

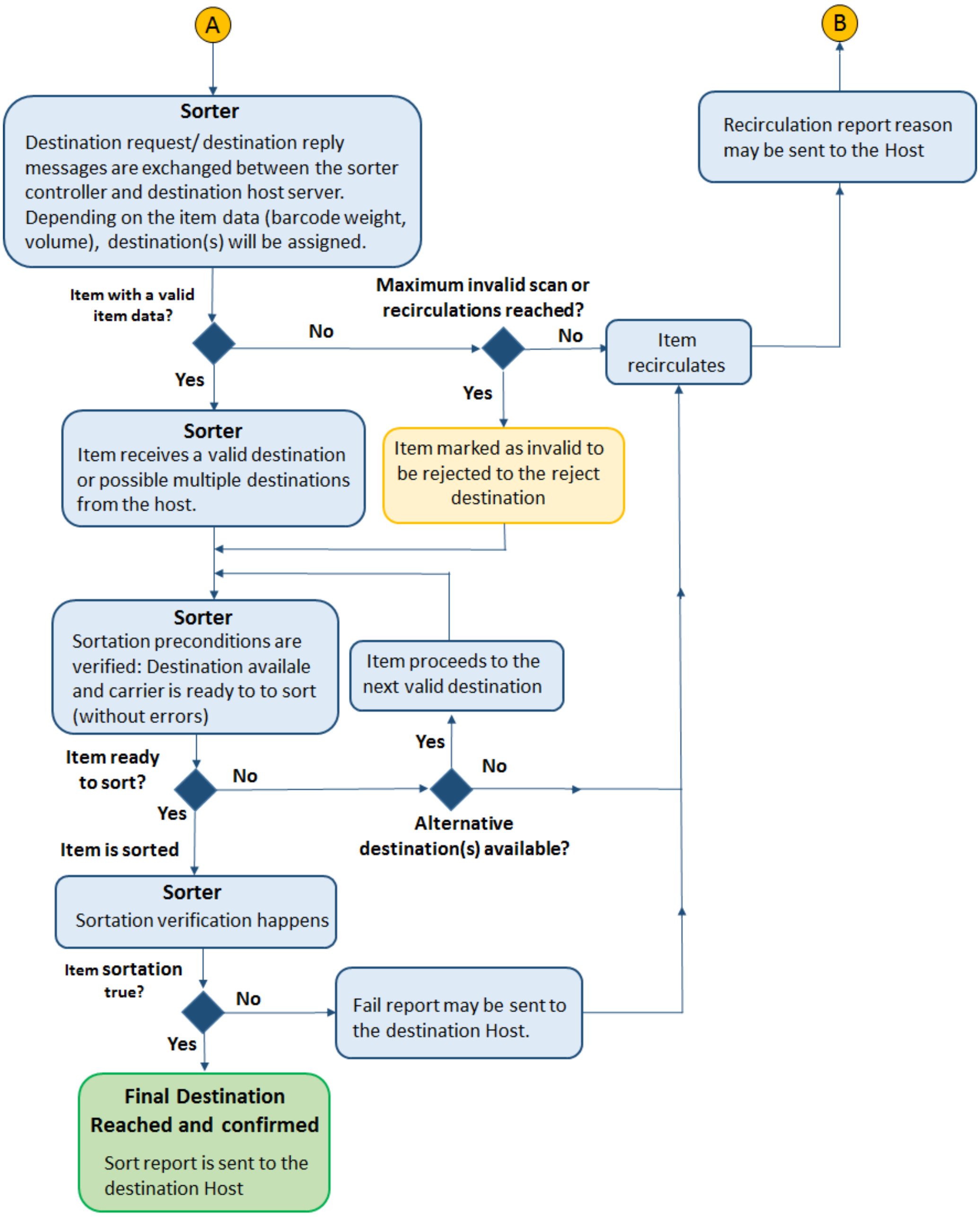


Figure 4-4 *Cross belt sorter* item flow diagram.

In normal operation conditions the *Cross belt sorter* controller doesn't assign destinations to items by itself. The destinations are always set by an external destination host server.

Just in special conditions the *Loop sorter* controller assign destinations, such as, if an item was detected to be incorrectly positioned on the sorter and it is not possible to recover it automatically, or if an item is present for extensive time on the system.

4.3. Cross belt sorter technology

The *Loop sorter* as defined previously is an infinite loop of carriers connected to each other on top of a track, where items can be sorted. However this automation system can be composed by many other different components. In this subchapter it will be explained the most common electromechanical components, scanning and screening solutions, type of controllers and communication protocols commonly used.

4.3.1. Electromechanical components

4.3.1.1. Carrier:

Each carrier is composed by two main components, the carrier chassis and the carrier deck.

Carrier chassis – is sustaining and guiding the movement of each carrier. It is mainly composed by guiding wheels (horizontally aligned) and support wheels (vertically aligned). It is also composed by permanent magnets (when using linear synchronous motors to move the sorter) on the bottom surface of the chassis, so that the carriers can be moved by the magnet field created by the linear synchronous motors.

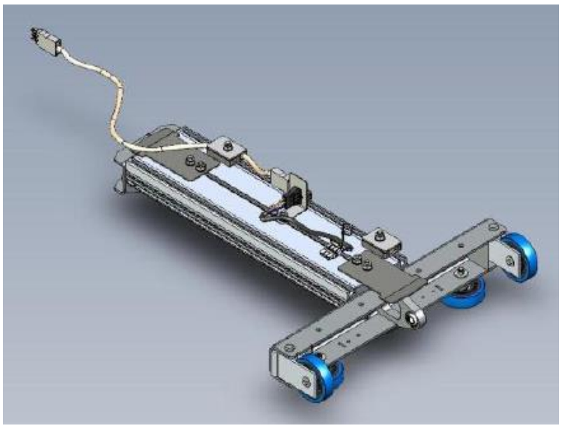


Figure 4-5 *Cross belt sorter* carrier.

Carrier deck – has the main function to transport items and sort them on the requested position. It is mainly composed by a cross belt (able to move in two directions), a controller and a motor. There is also a group of other mechanical components to create the movement on the cross belt, such as, pulleys, rollers and transmission belts.

Figure 4-6 Cross belt deck – SCS1500.

4.3.1.2. Sorter track

The sorter track has the main function to support the sorter, guide it when moving and provide power to each carrier unit. On each sorter track there is a powered rail where each carrier connects to, in order to power its carrier motor unit and controller.

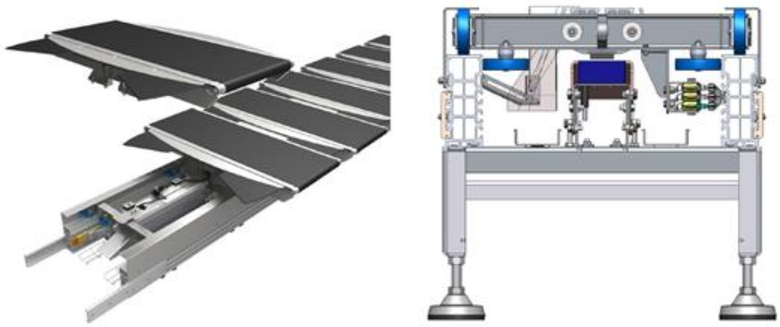


Figure 4-7 *Cross belt sorter* track view with carriers.

4.3.1.3. Linear Synchronous motor

Installed inside the track and is composed by three linear motor units and one encoder unit, which detects the magnetic polarization of the multiple permanent magnet present on each carrier. When the sorter is running different magnetic polarizations are detected by the encoder, this pulses time-based are converted to speed unit. Since the linear synchronous motors know the magnetic polarization of each permanent magnet passing over it, it can control accurately the sorter speed, making it to start, stop or maintain the same speed. The speed input and speed output are managed by the *Cross belt sorter* system controller.

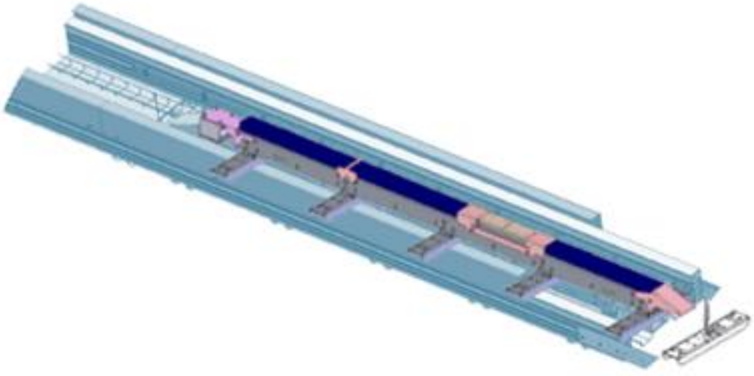


Figure 4-8 Linear synchronous motor.

4.3.1.4. Common conveyors types

Besides the *Loop sorter, Cross belt* systems are generally composed by other secondary types of conveyors. It will be referred on this subchapter the most commonly used, such as, conveyor belts, roller conveyors, and telescopic belts.

4.3.1.4.1. Conveyor belts

Conveyor belts are one of the most common ways to convey different materials. Generally, it consists of two or more pulleys carrying an endless loop of a belt conveyor that is moving according to movement of the pulleys. Each conveyor belt have a drive pulley which is connected to a gear box and this one connects to an electric motor, allowing the conveyor to run.

In the cases that item tracking accuracy is very important, the conveyor belt motors are mostly powered by frequency controllers. The rapid response, possibility to accelerate and decelerate in an accurate way are very important factors. For the cases that item tracking is less critical and the belts operate in a more constant speed, motors can be powered by a Direct On Line (DOL) drives or other available method.

In most conveyor belts it is possible to have attached to the conveyor an encoder, consisting on a wheel attached to the surface of the conveyor belt. When the belt moves the encoder unit sends time base input pulses to the *Cross belt sorter* controller, converting the pulses to speed and allowing the system to monitor and control the related section accurately.

Despite the common characteristics between belt conveyors, they can still have different shapes, grip surface and lengths, depending on its appliances.

Figure 4-9 Conveyor belts.

4.3.1.4.2. Roller conveyors

Generally powered by a single shaft, roller conveyors are very commonly used and they have some specific applications where conveyor belts cannot be used:

- Skewed roller conveyor design, has the function of aligning items correctly on the conveying lines to be transported along the downstream sections, preventing eventual operational errors;
- Present in discharge lines from a *Cross sorter* or other conveying machine where items are transferred in a considerable speed. For this cases roller conveyors have the advantage of allowing items to slip during the initial transition, and at the same time pull items to the desired direction, in case the rollers are driven by a motor;
- Compared to conveyor belts, roller conveyors can be cheaper, easier to maintain and to replace parts, easy installation and less noise during operation;
- As a downside, roller conveyors are not specifically designed to keep items in tracking on a higher speed and compared to the conveyor belts there is less conveyability for a wide range of items, such as small products or items which can slip easily on the rollers general metallic surface. Due to that it is quite common to convey on the roller conveyor sections, totes, where different items can be placed inside and conveyed.

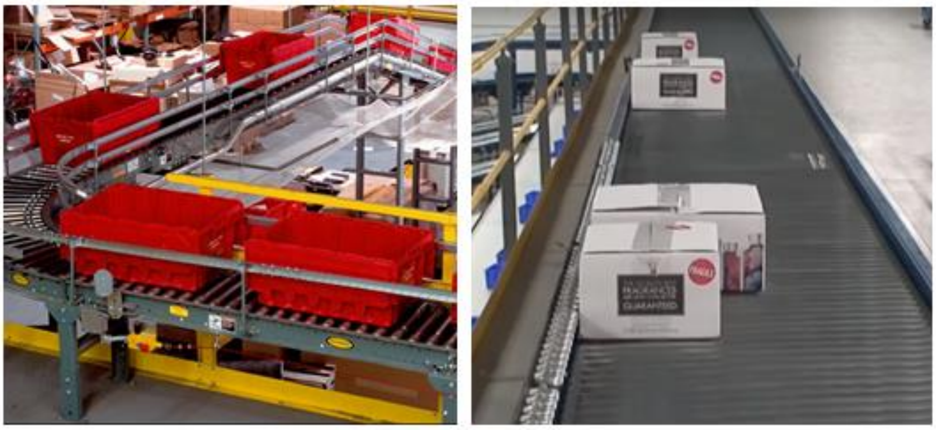


Figure 4-10 Roller conveyors.

4.3.1.4.3. Telescopic belt conveyor

A telescopic belt conveyor is generally used when loading and unloading items to/from vehicles. Its great characteristic is the length adjustment functionality which allows operators to handle parcels in easier and safer way, where items are placed close to the drop-off or take-away point. Another functionality is the passivity of item buffering when loading to vehicles, this allows the related upstream output to sort more items, before it becomes full. The main benefits of a telescopic belt conveyor are: an improved ergonomic working condition, with a more safe and reliable operation, faster loading and unloading, increasing the capacity of the system.

Figure 4-11 Telescopic belt conveyor.

4.3.2. Scanning, weighing and screening solutions

Cross belt systems are also complemented with different types of scanning, weighing and screening solutions depending on the system requirements and design.

4.3.2.1. Scanning solutions

Depending on the system design and requirements different solutions may be incorporated in the conveyor system, but the scanning solutions can be divided mainly in the barcode scanner and the volume scanner solutions.

4.3.2.1.1. Barcode scanner

One of the less complex barcode scanner solutions is the manual hand scanner, which allows operators scan items manually.

In order to improve system efficiency and capacity, more advanced automated barcode scanning solutions may be assembled directly on the conveyor systems, allowing items to be scanned during its transportation along the different conveyor lines. Depending on the scanning functionality intended and item characteristics a different range of scanners may be used. Bellow it is mentioned a general resume of the most used automated scanner solutions:

- Delimitated surface area barcode scanner – is the less complex automated barcode scanner and as the name indicates it scans the barcode on a predefined item surface area with limited focus possibility. This type of scanners are normally located on the side of conveyor lines where the distance from scanner to the items is generally always constant and known. Regarding its applications, can be several, but as example this type of scanners have a very good use on conveyor lines which sort totes (containing items), with fixed labelling position or on conveyor lines where there is an automated printing label machine placing labels on fixed position of every item and the scanner is used for label confirmation afterwards or before;
- Bottom barcode scanner – is generally located in the in between two conveyor sections on the bottom side. This scanners have the purpose to scan the full bottom surface of each item when being transported along the conveyor lines. As application example this scanners can be used for items that have more than one label (including invalid labels for the related conveyor system) and the operators don’t need to dedicate time to analyse which item surface has the correct label before placing them on the conveyor lines. For this same example scenario the conveyor system is generally complemented with a barcode scanner tunnel;

- Barcode scanner tunnel – as the name indicates the barcode scanner tunnel is composed by different scanners units that synchronize with each other. Generally is the most advanced barcode scanner type that can be found in a conveyor system. The less complex versions of this type of scanner have only one scanner unit, being able to scan only one or two surfaces from an item at the same time. However the most advanced barcode scanners tunnels, have more scanner units and can scan fully the five visible sides of an item at the same time, independent of its dimensions and position on the conveyor. This type of scanners can read barcodes on a wide range of products (small and big), since they can generally detect the item dimensions and position on the conveyor, being able to adjust the focus of every single scanner unit for each single product. Barcode scanner tunnels can be found on systems with variable item dimensions and unpredicted label position. Each *Cross belt system* has generally at least one barcode scanner assembled on the *Loop sorter*.

Figure 4-12 Five side barcode scanner tunnel.

4.3.2.1.2. Volume scanner

As the name indicates, volume scanners have the purpose to measure the volume of each item. It can be assembled at the same position of the barcode scanner tunnel on the *Loop sorter* and may be part of a full scanner tunnel solution, having the ability to detect each single product dimensions and read barcodes.

4.3.2.2. Motion weighing scale

Is a conveyor with the integrated function of being able to weigh items when they are being conveyed. The weighing scale conveyor besides its similarities to a regular conveyor section has its own controller to weigh products and consequently is interfacing with the conveyor system main controller. To insure proper item weighing it is crucial an accurate item tracking and gap control between items.

Figure 4-13 Motion weighing scale conveyor.

4.3.2.3. Screening machines

Screening machines may vary from conventional manual operated machines to a fully automated conveyed solution. The biggest advantage of having an automated conveyed machine is the increase of the system capacity. Nevertheless of its higher capacity, this machine still needs to obey the same standards, such as a work station position where qualified personnel analyse every single item and have the possibility to intervene in order to check manually the existence of non-authorized goods. The automated conveyed screening machine solution is only possible with accurate item tracking, gap control and proper interface with the conveyor system controller. As example, screening machines can be incorporated in express air hubs centres where goods need to be checked for theirs safety for legality.

Figure 4-14 Automated conveyed screening machines.

4.3.3. Controllers and other nodes

In the *Cross belt system*, as in any other automated conveyor system is characterized for its considerable amount of different node types. On the low level controls, a main controller reads and writes on different nodes, consequently interfacing with different components, such as, actuators, motor drives, photocells, relays, encoders, etc.

In order to operate the machine it is required a user interface to allow system operators to start/ stop the machine as well diagnose faults and know the current system status. This interface can happen via a simple compact *Human-machine Interface* (HMI) display or a more advanced solution, like a *Graphic User Interface* (GUI) where different systems elements can be analysed and studied. However it depends on the machine supplier and the designed solution, since there is wide variety of possible solutions, being even possible to have a tailor made GUI for a system.

For large systems, the HMI/ GUI is complemented with a *Supervisory Control and Data Acquisition* (SCADA) and/ or other statistical application tooling with the objective of analysing system performance, such as, number of errors and system availability. SCADA, complements the regular HMI/ GUI by allowing to have in one single application different subsystems part of a complete facility. SCADA generally is also more illustrative compared to a regular HMI / GUI, and it facilitates the supervision of the full facility by helping system operators to provide a quicker response when system faults occur.

Figure 4-15 Siemens controllers and appliances.

Regarding the low level system controllers, there is a quite variety available in the market and each one as its own characteristics and advantages. It will be referred in this subchapter three general controller types: embedded systems, programmable logic controller (PLC) and industrial PC.

4.3.3.1. Embedded system

An embedded system is a combination of computer based system with hardware and software. Depending on the function, an embedded system can be programmable or with fixed capability. An embedded system can be a microcontroller or a microprocessor. A microprocessor the central control unit (CPU) and is used mostly for arithmetic and logic functions. A microcontroller is a compact integrated circuit, containing a CPU, memory and input and outputs peripherals.

Compared to casual computers, microcontrollers have the advantage of being more compact, with lower power consumption and a more attractive price. However, microcontrollers have a CPU with less capabilities and memory, making them more suitable to execute specific functions in most of the cases.

Figure 4-16 Arduino embedded system.

4.3.3.2. Programmable Logic Controller (PLC)

As the name indicates is a *Programmable Logic Controller* (PLC), used in different automated industries appliances. This type of controllers are characterized for being rugged, with higher resistance to industrial environment and for their capability to operate in real-time. PLC has the function to set output actions according to the received inputs (from switches, encoders, sensors, etc) and programmed functionality. A PLC is able to control a full machine or complete facility, depending on its computing capabilities and desired appliances.

An important step when choosing a PLC and developing a program for an automated system is understanding the different PLC capabilities and the most important is the program scan cycle time. The PLC program executes continuously in cycle, in the beginning of every cycle input signals are copied to PLC memory and the program executes a defined sequence of programing blocks based on this inputs. More recent high-end PLCs can execute a considerable large program in few milliseconds, compared to older and outdated PLCs. Nevertheless, if the available range of PLCs still don't suit to control fully one system due to its large program, consequently due to a considerable large system or with complex functionalities implemented, there is the possibility split the system in different subsystems with more than one PLC, which they could eventually interface with each other.

Figure 4-17 Siemens S7-1500 PLC.

4.3.3.3. Industrial PC

Industrial PCs are rugged, suited for industrial environment depending on the application and can be placed inside cabinets and racks. Regarding its applications, it is used to control and monitor data as normal PLC. They have the capability to be integrated with I/O nodes and other compatible industrial devices such as HMI. An industrial PC, as normal home user PCs has the flexibility to use different operative systems (for example: as Linux, QNX or Windows) and run a particular existing software applications or custom developed applications.

Compared to a PLC, an industrial PC has the big advantage of a faster processing time, programs can be triggered by an incoming event, immediately calculating it and an output solution or task will be set. All of this process will happen without the need of running a program cycle. This leads industrial PCs to be more suited to control very time critical applications, to resolve more complex functions and consequently large programs compared to a regular PLC. However there is still the need to developed efficient program applications, especially for complex and large systems, since different applications or program functions can be triggered by several events at the same moment. As example, if the resolution of incoming events is not properly managed with efficiency, a set of complex calculations can be triggered at the same time and as consequence it can lead the CPU to overload its memory capability, causing delays on processes that should be calculated in a faster speed and could eventually lead to the full stop of the machine, with inconsistent errors.

Figure 4-18 Industrial Siemens SIMATIC PC.

4.3.4. Communication protocols

A communication protocol consists in a number of rules that allow two or more devices to exchange data (send and receive) and understand it. The protocol itself defines the syntax rules and structures of the messages. It may also apply error recovery or receiving verification methods.

In a *Cross belt system*, a wide variety of communication protocols can be used to communicate with different devices, depending on the machine developer and supplier. In this subchapter it will be referred the most common communication protocols used not in the *Cross belt systems*, but also in other automation solutions.

However, before exaplaning the different communication protocols it is important to understand the different communication layers and their functions. The different communication layers will be studied using the *Open Systems Interconnection* model – OSI model.

4.3.4.1. Open Systems Interconnection model - OSI model

The Open Systems Interconnection (OSI) model defines how the communication between two or more devices take place, over seven defined layers. OSI communication layers are organized in inarchy, meaning that each layer serves an upper one. Specification ISO/IEC 7498-1.

7 – Application
6 – Presentation
5 – Session
4 – Transport
3 – Network
2 – Data Link
1 – Physical

Table 4-1 OSI Layers.

1 – Physical – It defines the physical electrical or optical cable where the data is exchanged. It specifies, not only the type of material or connection, but also it refers to voltage, frequency and impedance;

2 – Data Link – Refers to the node-to-node data transfer. It not only validates the data, but it detects and corrects errors from the physical layer;

3– Network – Manages the logical addressing, the information in the data packets and the delivery of this data. The network has the function to connect different nodes together, allowing them to communicate to each other;

4 – Transport – Has the function to transfer variable data length packets from one node to another. It is responsible to "break" data in small packets from a node A to a node B (in case of necessity) and if one of the small packets is lost during transmission, it will re-sent it again in case of detection;

5 – Session – Establishes and manages the communication between end to end, between two devices. Before each device sends any data, each device must agree with the service and rules proposed in the session layer;

6 – Presentation – It is responsible to verify if each message has the proper format in order to the application layer understand it. The same happens when the presentation layer receives data from the application layer, it needs to be in the correct format before it is sent over the network. Beyond the message format verification, the presentation layer also converts the format in case is needed;

7 – Application – Provides the necessary interface for the end user, supporting applications and user processes. It is also responsible for application services, such e-mail and other software services.

When it comes to classification of communication protocols regarding the OSI model, some communication protocols might not have certain OSI layers or have them combined in one layer.

4.3.4.2. Industrial Ethernet

Ethernet technology was standardized by IEEE 802.3 - a working group of *Institute of Electrical and Electronics Engineers* (IEEE). It defines physical layer and data link layer's medium access control (MAC) of a wired Ethernet.

Ethernet is used on local area networks (LAN), metropolitan area networks (MAN) and wide area networks (WAN).

Industrial Ethernet (IE) is the application of the Ethernet in an industrial environment for real time automation. The equipment's used are expected to handle a heavy duty environment with different temperatures, noises and vibrations. Due to that is required more rugged connectors, cables compared to the Ethernet used in the office.

IE is also characterized for its determinism, meaning that it guarantees that messages will arrive within a desired time window, compared to the standard Ethernet that is not deterministic. Determinism is crucial for a smooth production cycle and needed to prevent industrial network jitter, which can cause delay or error during production.

Some protocols that use Industrial Ethernet are PROFINET, EtherNet/IP and Modbus TCP.

4.3.4.2.1. PROFINET

PROFINET was developed and currently maintained by Profibus & Profinet International organization. It communicates over the Industrial Ethernet and it was designed to operate on real time applications with determinism.

PROFINET has tree technologies: TCP/IP; RT (Real-Time); IRT (Isochronous Real-Time).

PROFINET TCP/IP – Is used for non-real time applications, such as making sure that devices keep communicating and the operation keeps in progress. Since it is not deterministic it cannot insure that all the messages will arrive within an expected time window. Cycle times can go up to 100ms.

PROFINET RT – It skips the TCP/IP, taking messages from the Ethernet physical layer to the application layer, PROFINET RT, providing high precision determinism. It's mostly used on PROFINET IO messages up to 10ms cycle times.

PROFINET IRT – is similar to the PROFINET RT, but it takes the determinism a bit further and it can have cycle times lower than 1ms. PROFINET IRT is suitable for applications where motion control is critical.

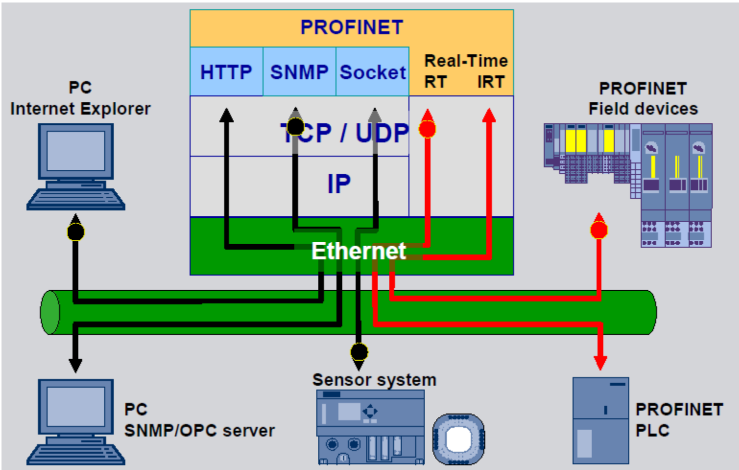


Figure 4-19 PROFINET communication layers.

4.3.4.2.2. EtherNet/IP

EtherNet/IP is the *Common Industrial Protocol* (CIP) implemented over standard Ethernet (IEEE 802.3 and the TCP/IP protocol suite). The "IP" in Ethernet/ IP stands for Industrial Protocol, having a different meaning to the commonly used "IP", as example for "IP address".

EtherNet/IP and CIP technologies are managed by ODVA - formerly Open DeviceNet Vendors Association.

Common Industrial Protocol (CIP) – Is an object oriented protocol designed for automation applications. It has a comprehensive set of communication services for automation applications: control, safety, synchronization, motion, configuration and information.

EtherNet/IP implements CIP at the OSI session layer above and adapts CIP to the specific EtherNet/IP technology at the transport layer and below. The network architecture is shown in the figure 4-21 bellow.

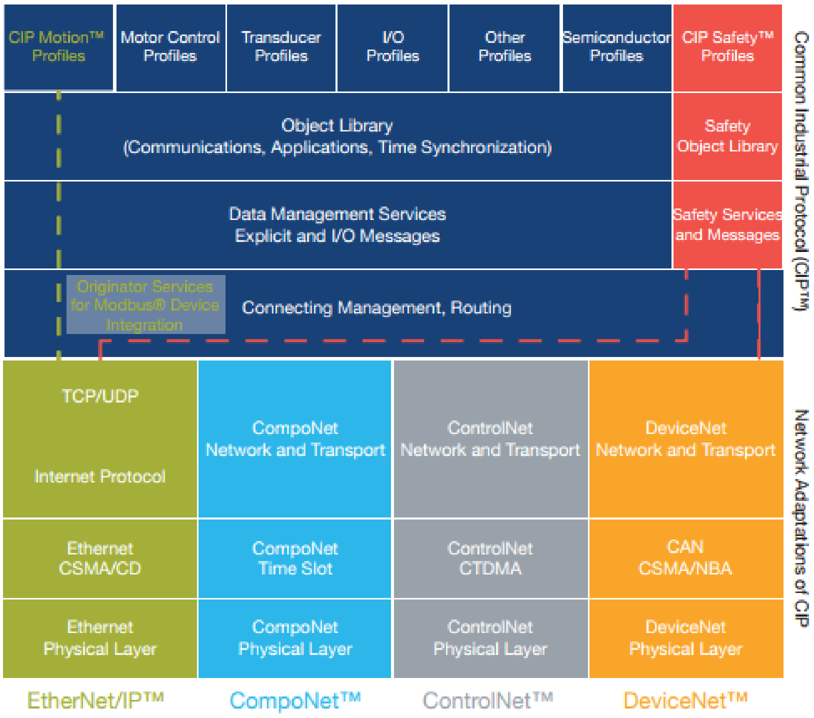


Figure 4-20 EtherNET/IP Communication Layers.

EtherNET/IP uses both TCP/IP and UDP/IP messages depending on the application:

TCP/IP is used to send implicit messages between one or more devices which requires acknowledgement of the client-server type.

UDP/IP explicit messages work as real-time collecting data from each node device present on the production floor.

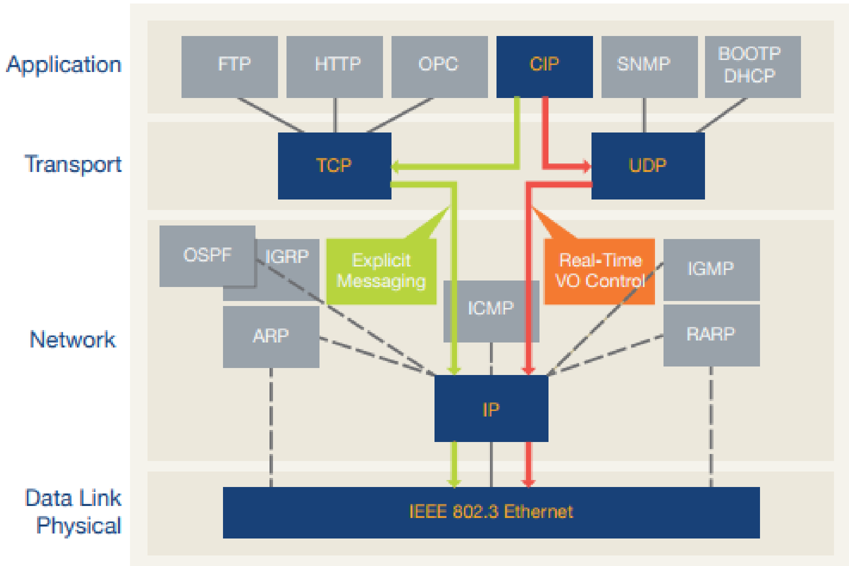


Figure 4-21 EtherNET/IP explicit and implicit messaging diagram.

4.3.4.2.3. MODBUS TPC

MODBUS TCP/IP is the use of the *Transmission Control Protocol* (TCP) and *Internet Protocol* (IP) simultaneously to send and receive data. In simple terms, is the MODBUS RTU modified so it can be transmitted over a TCP/IP network instead of a serial line. The server can be reached via its IP instead of MODBUS ID or address.

On MODBUS TCP, the *Master* is the *Client* and the *Slave* is the *Server*. *Server* waits always for the *Client* to start the connection. Once a connection is established, the *Server* then responds to the queries from the *Client* until the *Client* closes the connection.

4.3.4.3. Serial Communication Protocols

4.3.4.3.1. MODBUS RTU

MODBUS *Remote Terminal Unit* (RTU) is an open serial (RS-232 or RS-485) communication (sending one bit at a time) protocol developed by Modicon (now Schneider Electric) for its programmable logic controllers (PLC).

MODBUS RTU messages are a simple 16-bit CRC (Cyclic-Redundant Checksum), making it reliable. Due to this simplicity, the basic 16-bit MODBUS RTU register structure can be used to pack in floating point, tables, ASCII text, queues, and other data.

The Modbus Master can request or write information on different Modbus Slaves. On a Modbus network, there is one Master and the slaves can be addressed from 1 to 247. However, via RS-485 normal network can exist only 32 nodes. In MODBUS RTU each device speaks at the time, there is no multiple devices speaking, that’s the reason of one only Master via RS-485.

On MODBUS RTU, each node can send the following type of data:

- Coil, 1 bit;
- Discrete input, 1 bit;
- Input register, 16 bits;
- Holding register, 16 bits.

As advantages compared to more sophisticated protocols, the message packages are quite light, requiring a CPU with less memory and there is a big compatibility with other devices.

As disadvantages, the MODBUS RTU, is intended to transmit only data, in order to send parameters such as point name, resolution or units a more modern and sophisticated protocol should be used.

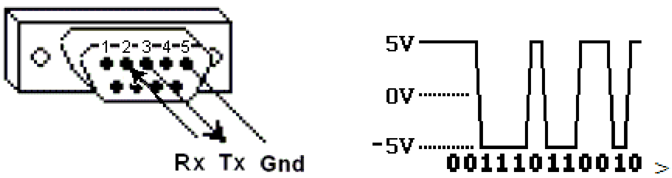


Figure 4-22 MODBUS RTU via RS-485.

4.3.4.3.2. <u>MODBUS/ASCII</u>

Is similar to MODBUS RTU, but has few differences. MODBUS/ASCII messages are encoded in ASCII format, being easier to read for analysis purposes, and MODBUS RTU messages are structured in binary code.

On MODBUS/ASCII uses a *Longitudinal Redundancy Check* (LRC) checksum for error detection and messages start with a flag ‘:’ and it ends with a CR/ LF combination.

On MODBUS RTU to differentiate start and end of each message uses 3.5 chars silence space.

4.3.4.3.3. PROFIBUS

PROFIBUS is serial fieldbus based in the automation standard of *PROFIBUS & PROFINET International* (PI) and it is used on Siemens automated systems. PROFIBUS connects controllers with decentralized nodes, such as sensors, actuators, and encoders. Within PROFIBUS there are two types of technologies: Profibus DP and Profibus PA

Profibus DP (Decentralised Peripherals) – Uses one Master with remote I/O modules on the production line. The I/O from the production ground floor are not connected directly to PLC, but to an *Interface Module* (IM) and this one connects to the PLC via a RS-485. It uses a two core cable and has speeds between 9.6kbit/s to 12Mbit/s.

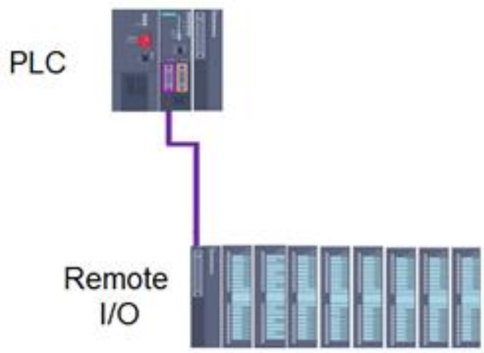


Figure 4-23 PROFIBUS DP hardware setup.

Profibus PA (Process Automation) – is used on safety environments, by monitoring safety devices. It has the same protocol as PROFIBUS DP. Regarding communication transmission speeds it is fixed 31.2kbit/s via two core screened cable, much slower compared to PROFIBUS DP.

4.3.4.4. Other Communication Protocols

4.3.4.4.1. AS-Interface

Actuator Sensor Interface – AS-Interface or AS-I, maintained by AS-International Association, is a versatile, robust (noise resistant), low cost and a “smart” cabling solution network. It is used in PLC and PC-based automation systems to interact with simple I/O devices such as actuators, photocells, encoders, and push buttons.

AS-I network works with the Master-Slave principle, supporting one master per network and it has the possibility to connect up to 62 slaves, with a total maximum of 496 inputs and 496 outputs.

In terms of application, it is relatively simple, each slave connects to a single 2-wire cable, with 4 bits data available and power at the same time. For applications which is required to force a 24Vdc output (for example a signal lamp or an actuator), it is necessary to connect the slave to an extra 2-wire black flat cable which gives the extra necessary power to set up the output. The extra power cable it is powered generally from a power supply.

One of the downsides of the AS-interface is that the cycle time can be too long (5ms) for specific real time automation applications, such as, high resolution encoder signals.

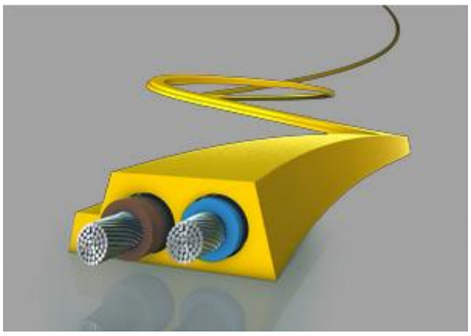


Figure 4-24 AS-Interface 2-wire flat cable.

In terms of practical implementation, AS-I Master works as a gateway in most of the cases, for example, AS-I to PROFINET gateway, meaning that the AS-I Master is a node on the related PROFINET network as represented in the Figure 4-26 bellow.

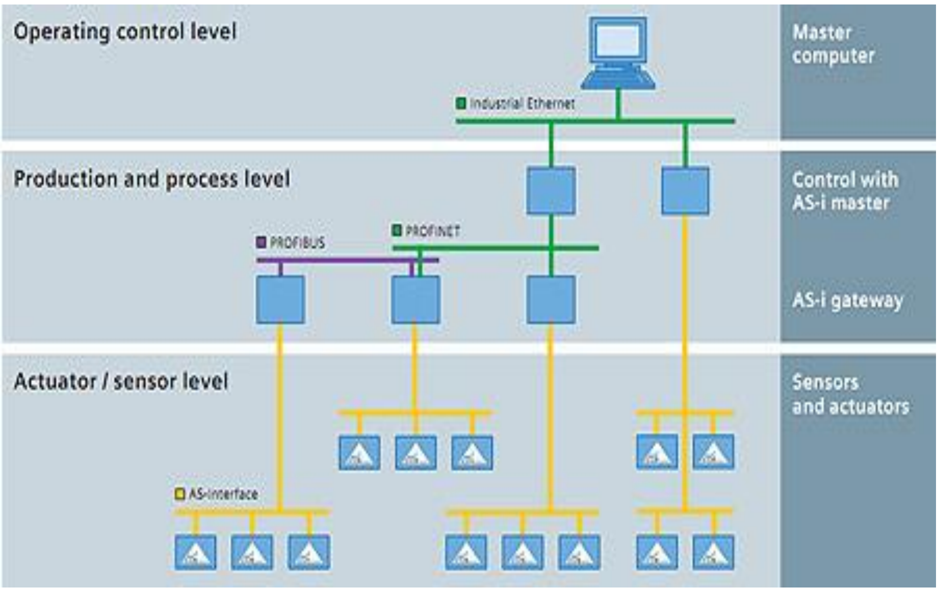


Figure 4-25 AS-Interface implemented on PROFINET.

Regarding CAN specifications, ISO 11898 series defines the physical and data link layer of serial communication technology called of CAN - Controller Area Network.

4.3.4.4.2. <u>CAN</u>

Controller Area Network (CAN), was developed initially by Robert Bosch GmbH for the automobile sector and the ISO 11898 series defines the physical and data link layers of CAN. It is a robust standard protocol which allows embedded systems and other devices to communicate without a host computer.

CAN is a standard multi-master serial bus communication system, allowing devices inside the same network to communicate to each other without Master. The devices are called *Electronic Control Units* (ECUs), also known as nodes. An ECU can be a simple I/O device or an embedded controller with more sophisticated software or even a gateway to convert for instance CAN to PROFINET, or vice-versa.

All ECUs connected to the network can listen to all the messages, however they just take action when the message is addressed to them.

All nodes are connected to each other through a two wire a twisted pair bus, one CAN-high and one CAN-low, using the differential communication method. The CAN bus must have resistors to suppressed reflections and maintain the voltage between the twisted pair correct. On the high speed it is used 120 Ω termination resistors on both ends.

ISO 11898-2 - High Speed CAN has baud rates from 40 Kbit/s to 1 Mbit/sec, depending on cable length.

ISO 11898-3 - Low Speed/Fault Tolerant CAN has baud rates from 40 Kbit/s to 125 Kbits/sec.

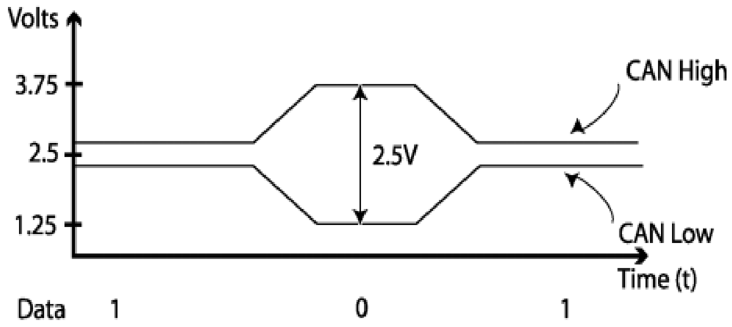


Figure 4-26 CAN twisted pair graphical representation, CAN High and CAN low.

CAN, has two specifications CAN 2.0 A with standard 11 bit identifier and CAN 2.0 B extended with 29 bit identifier.

In CAN bus, only one device can send a message at a time. In order to define the different devices message priorities, CAN uses the arbitration method. It is imperative that each device in the bus to be synchronized to each other when using the arbitration method in CAN.

In CAN bus the recessive bit has value '1' and the dominant bit has value '0'. The dominant bit overnights the recessive bit on the bus. Each node that is transmitting data, compares the output data that is sending to the current data on the bus. If there is a difference, it means that there is other device transmitting.

4.3.4.4.3. CANopen

CANopen is a high-level communication protocol and device profile specification used in the automation sector based on the CAN protocol. CANopen was developed by *CAN in Automation*, CiA. The general definitions for CANopen are referred in the CiA DS 301 specification from CiA.

In terms of OSI communication systems model, CAN itself covers the physical layer and the data link layer. CANopen covers three logical parts: CANopen protocol stack which handles communication on CAN bus; Application software to process the hardware interfaces and internal control functions; CANopen Object Dictionary (OB) which interfaces the application software and stores the device.

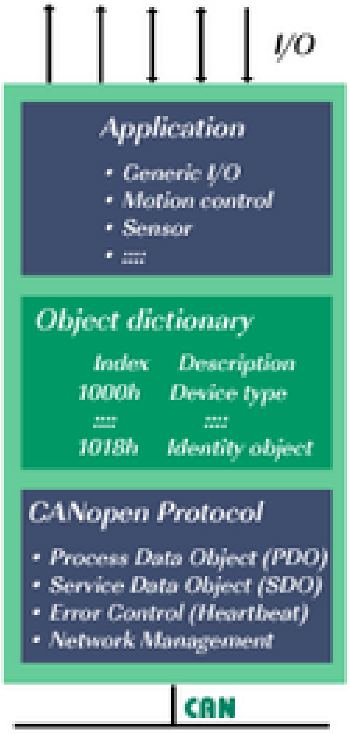


Figure 4-27 CAN and CANopen OSI model.

<u>Object Dictionary</u>

The Object Dictionary is listed on a standardized format and the CANopen standard defines a 16-bit bit index and an 8-bit sub-index. It is used 4 digit hexadecimal for the bit index value.

Index	Description
0000h	reserved
0001h - 025Fh	Data types
0260h - 0FFFh	reserved
1000h - 1FFFh	Communication object area
2000h - 5FFFh	Manufacturer specific area
6000h - 9FFFh	Device profile specific area
A000h - BFFFh	Interface profile specific area
C000h -FFFFh	reserved

Figure 4-28 CANopen Object Dictionary table.

<u>CANopen communication</u>

A CANopen protocol stack implements several CANopen COBs that are communicated with one of the CANopen bit-rates. The CANopen communication objects enable system designers to transfer control information, to react to certain error conditions or to influence and control the network behavior.

The CANopen comprise:

- Service Data Object – SDO;
- Process Data Object – PDO;
- Network Management – NMT;
- Special functions;
- Error control functions.

4.3.5. Network topology

Due to the wide variety of devices and different subsystems inserted in the *Cross belt sorter* the network topology can be quite complex. As represented in the figure 4-30 the system is divided in Low Level Controls (LLC) network where the Cross belt sorter is allocated with its slaves and High Level Controls network where the Host server, SCADA and other diagnostics tooling can be found and are interfacing with the *Loop sorter* controller. Also in the HLC network there is normally the VPN connection.

In the LLC network there is a main network (for example: PROFINET) where the main controller communicates with other system nodes, including a communication gateways which have the functionality to convert the communication protocol from the main network to a secondary communication network, as example the AS-I gateway which enables the main controller of the system in PROFINET to control end read diagnostics from a slave in AS-I communication protocol.

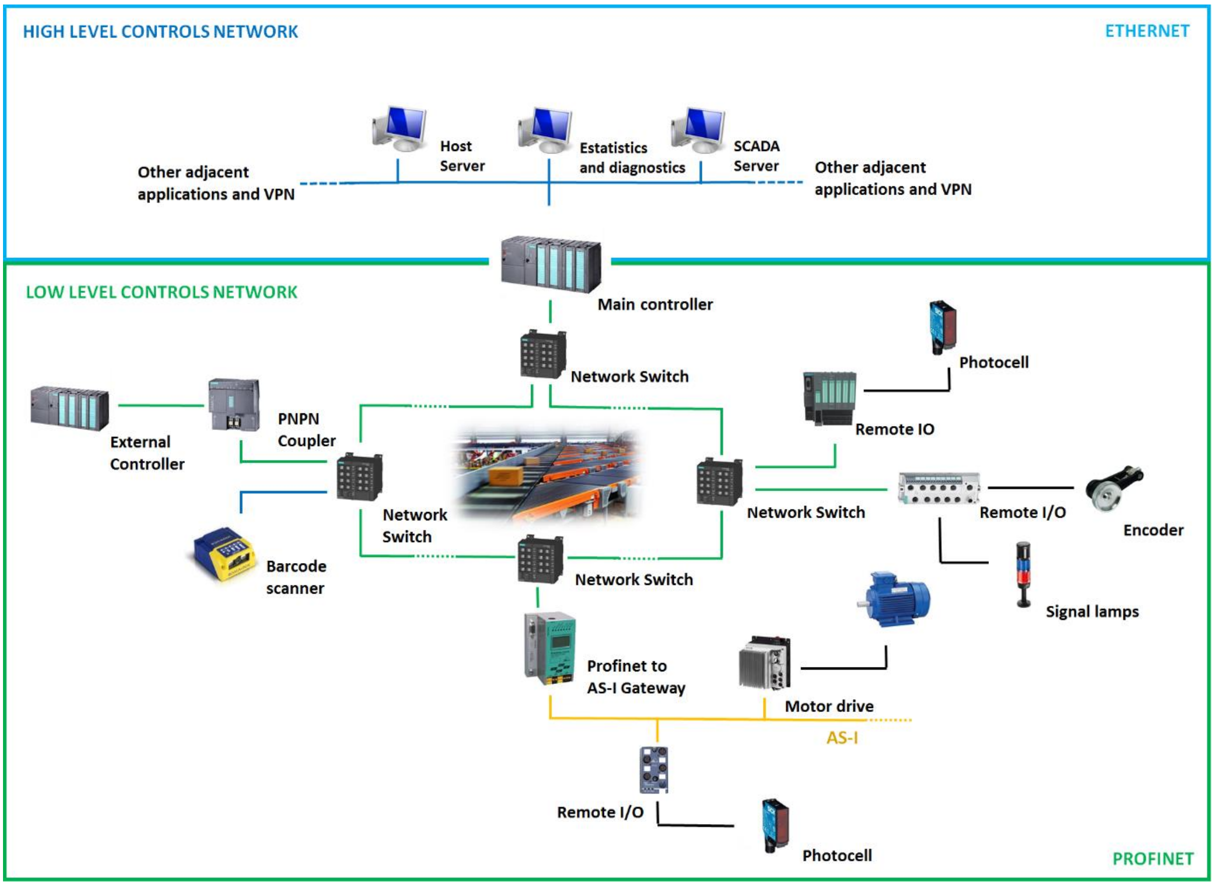


Figure 4-30 Network topology representation.

4.3.6. System special functionalities and item behaviour:

In this sub-chapter it will be referred in more detail item behavior in different circumstances and important system functionalities when conveying items.

4.3.6.1. <u>Item tracking</u>

Item tracking is present in most conveyor systems, including in the *Cross belt sorter*. In order to sort items accurately it is mandatory to know where each item is located at any moment in time. Item tracking has two important features:

- Allows the system controller to collect data from each item (example: weight, dimensions, barcode, item type, destination, etc) along its path over the different conveyors present in the system. The item data can be used not only to sort items accurately, but also to create exceptional system operational errors, for example, if an item is over dimensions or weight. Item data is also commonly used when receiving or handing over items to other conveyor systems;

- Since the system controller knows where each item is located and its transportation length, it can calculate accurately gaps between items (if placed on a conveyor with reasonable grip, as a conveyor belt), maximizing the system capacity and preventing operational errors.

However, in order to implement item tracking accurately in a conveyor the following is required:

- Electro-mechanic components – Update sensor (example: photocell or light grid sensor) and an encoder to detect the conveyor speed;
- Information to be known – Length of the related conveyor and its real speed, position of the update sensor, electric motor acceleration and deceleration.

On low capacity conveyors or with more stable speed, the physical encoder can be dismissed, having the possibility to save some costs. For this case, the system controller will use the physical default speed value by knowing the related conveyor maximum speed and the motor acceleration and deceleration. The main disadvantage of not having an encoder is that, the comparison between the default speed value and actual real speed (measured with an encoder) is no longer possible via software program. If the related conveyor belt is being slowly damaged or the motor is not operating accordingly, the fault will take longer to be detected. Beyond that, item tracking can start to be less accurate over time without a real speed encoder device.

Other important fact to refer is that, on the conveyor lines with item tracking implemented the conveyor system controller normally have a configurable expectation window margins for each update sensor, a maximum too early and too late. This means that each item remains in tracking if it triggers the update sensor within the defined expectation window margins. If the an item arrives too late or too earlier relatively to the defined window margins and to what is expected, its tracking data will be lost and new item data will start to be generated from that moment onwards, as it would be a new item on the system.

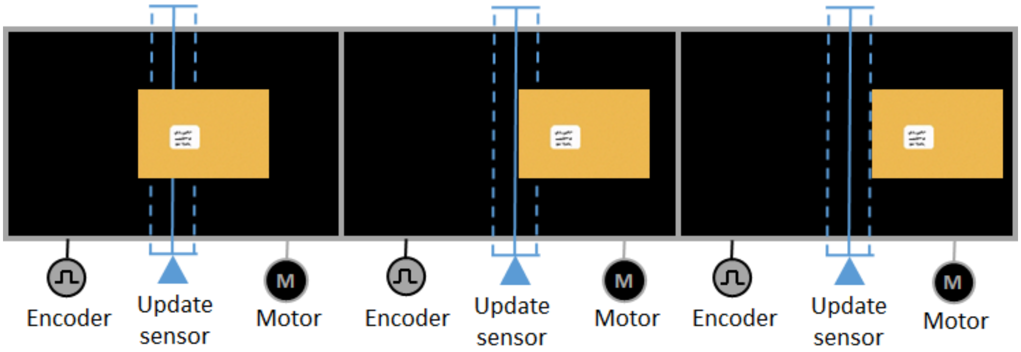


Figure 4-29 Item tracking, hardware components representation.

Regarding the item tracking calculations, the items positions can be calculated by the following linear motion equations:

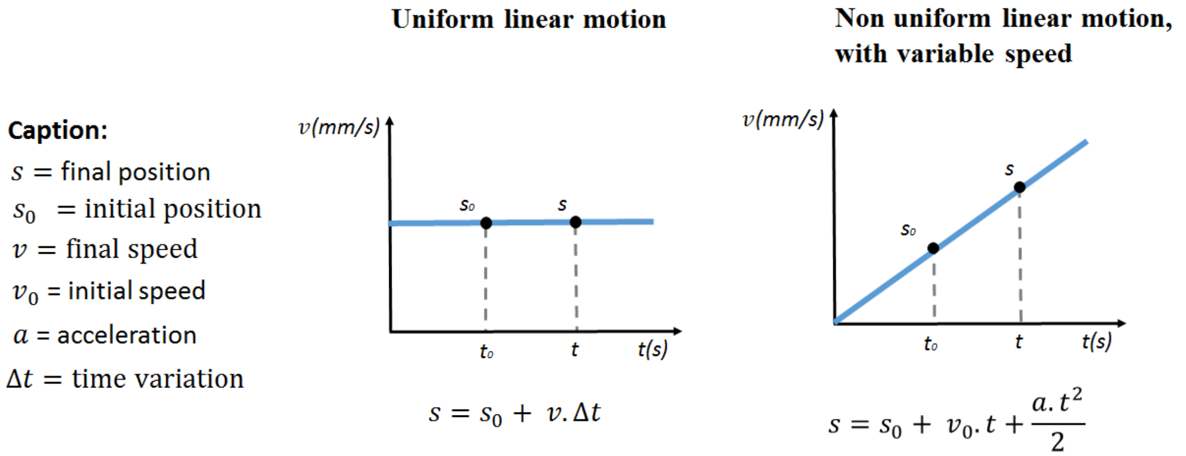


Figure 4-30 Linear motion equations.

4.3.6.2. Induction Process

An induction line or induct in a *Cross belt sorter* consists of a sequence of conveyor belts that load items on the sorter. As indicated earlier on the Figure 4-4 items can be loaded manually on inducts or delivered by an upstream conveyor system.

The induction process is one of the most complex processes in the *Cross belt sorter* system, since induction lines have the main function to deliver the maximum amount of items in the shortest period of time to the sorter. In order to achieve that, it is mandatory a precise time synchronization between the different induct elements and the sorter.

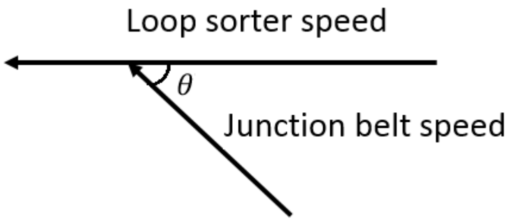
Induction lines can have slightly different design (number of conveyor belts, speeds, sensors, etc), depending on the system requirements (item type, sorter type and induct capacity required), but there are common characteristics and components among all of them: A light grid sensor to detect the shape and dimensions of each item, a junction belt with its triangular mechanical design allow inducts to be connected to the sorter, a combination of shorts belts with variable speed and a receiving or supply belt placed upstream to the light grid sensor.

Each induction line can be separated in two sub-zones: a transportation zone and an induction zone.

Transportation zone – has the function to transport each item with a minimum correct gap to the induction zone, making the necessary corrections if needed. It is important a correct minimum gap control between items in order to maximize the feeding capacity and to prevent system errors.

Induction zone – Is where the most complex part of induction process happens and has the name indicates, has the function to induct items into the sorter accurately.

Thus, at the start of the induction zone item dimensions, shape and position are precisely determined by the light grid sensor. With item dimension, shape and position determined the item allocation window is calculated. Thereafter, the system will look for the closest allocation match on the sorter, evaluating the necessary carrier(s) and their position relative to the item position on the induct. When an allocation match is found induction line will accelerate the short belts synchronously in order to deliver the item on the middle of the carrier(s). During the item handover from the junction belt to the carrier(s), the cross belt(s) on the related carrier(s) will rotate at the same time that the item is being transferred in order to have a smooth transition, without friction. The smooth item transition is ensured by the vector speed decomposition of the junction belt. It needs to match the sorter speed and it can be calculated as indicated on the figure 4-32 below:



$$Junction\ belt\ speed = \frac{sorter\ speed}{Cos(\theta)}$$

Figure 4-31 Junction belt speed calculation.

After the item allocation window calculated, if there is no allocation match found the item will wait on the most downstream possible position at the induct for a match.

It is important clarify that induction lines can detect exceptions, such as, items above dimensions and incorrect gap between items. For each exception each induction line will try to auto-recover (example: correcting item gaps) and if that is not possible the item(s) need to be removed manually or induction section will reject them automatically in case programed for this purpose.

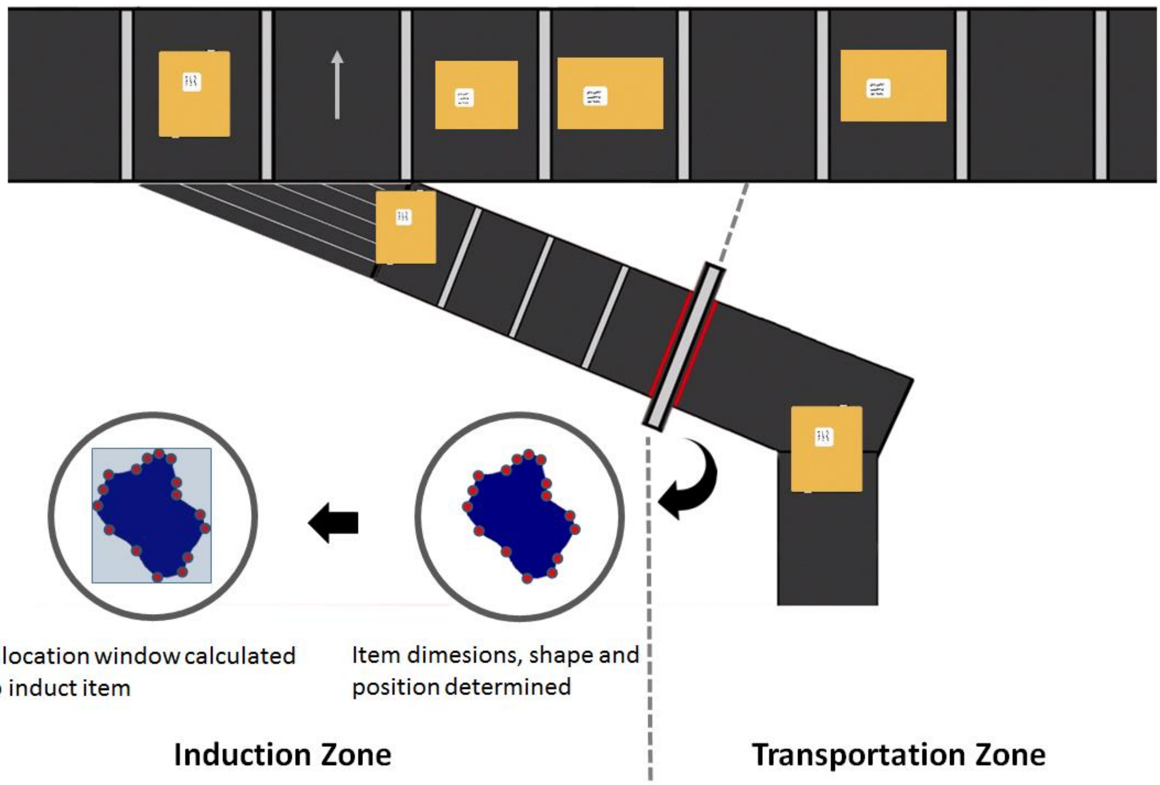


Figure 4-32 Induction line.

5. CROSS BELT SORTER – PROJECT EXECTUTION

Since November of 2014, I had the opportunity to execute and participate on fifteen *Cross belt system* projects spread all over the world. The projects were part of the following market areas: express, e-commerce and retail. Out of the *Cross belt system*, I had opportunity to work in one *Tilt tray sorter*.

Regarding the *Cross belt system* projects that I participated, in general there are some similarities, but within each system there are particular project specific functionalities, such as, *Cross belt sorter* length and type, different conveyor lines, interfaces (example: destination host server, automated weighing scales, scanning and screening solutions, etc) and different type of items to be sorted.

In this chapter I will describe the different project tasks that I was involved and necessary general steps to commission a *Cross belt system* successfully. Besides the different projects requirements, I describe a commissioning procedure which is applicable to all *Cross belt system* projects.

City, Country	**Year**	**Market**
Poznan, Poland	2015 and 2018	E-Commerce
Madrid, Spain	2015	Express
Moscow, Russia	2015	Clothing and retail
Sao Paulo, Brazil	2016	Express
Warsaw, Poland	2016	Express
Vitoria, Spain	2017	Express
Szczecin, Poland	2017	E-Commerce
Oslo, Norway	2017	Express
Wroclaw, Poland	2016	E-Commerce
Liverpool, UK	2016	Retail
Saint Petersburg, Russia	2017	Airport
Berlin, Germany	2017	Express
Moscow, Russia	2017	Express
Istambul, Turkey	2018	Express
Shanghai, China	2018	Clothing and retail

Table 5-1 Projects executed.

5.1. Project methodology – structure:

In this subchapter it is referred the project methodology for the *Cross belt system*. The project methodology described has the focus on the commissioning scope of the project. All project phases are very structured meaning that each project phase needs to be completed in a determined deadline before the next one. Each project phase serves as an input for the following phase. Due to the rigid project structure the project methodology used is the waterfall method.

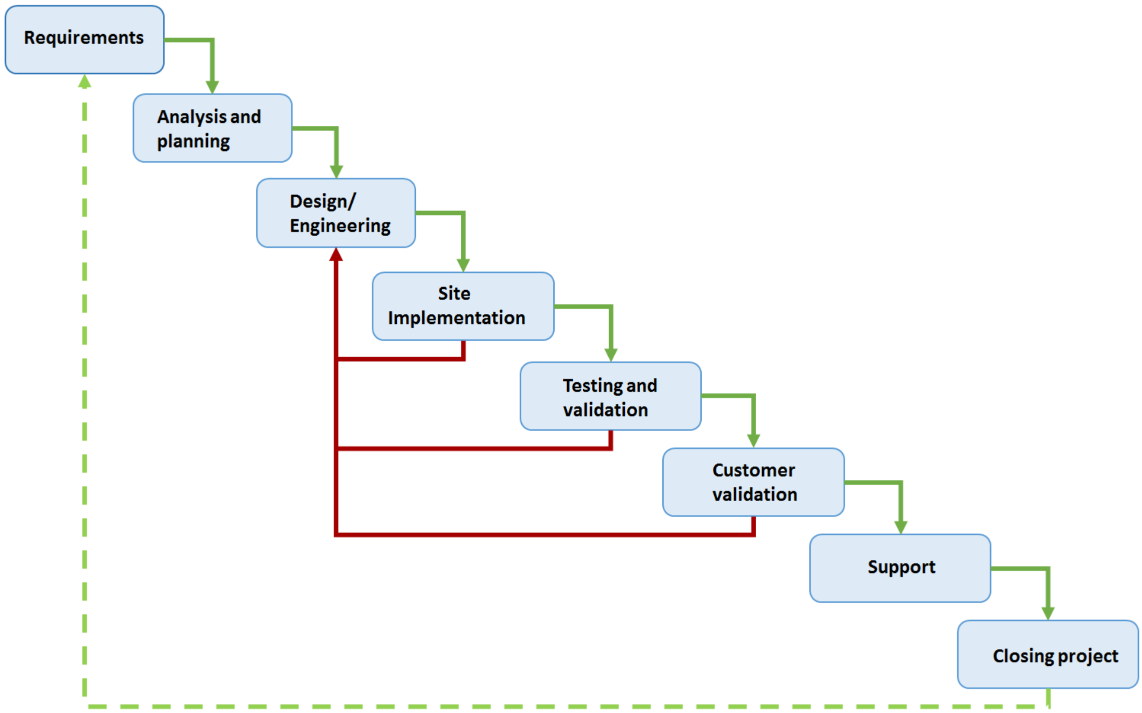


Figure 5-1 Project methodology.

5.1.1. Requirements:

All projects start with defined requirement specifications and it is very important that requirements be very clear and detailed since it will facilitate the project execution during all its multiple phases. As *Cross belt system* requirement examples: System capacity, *Loop sorter* speed, single induct line capacity, sorting accuracy rate definition, products to be conveyed, discharge profile definition, etc. As a specific requirement for the commissioning engineer is also the deadline to deliver the full system operation to the customer.

5.1.2. Analysis*:*

During this phase all project requirements should be analysed in order to create a more accurate plan and more accurate implementation. All non-standard functionalities must be clear.

5.1.3. Design/ Engineering:

During the engineering the program configuration for the *Cross belt system* should be prepared and all interface documentation specifications between the *Loop sorter* and external controllers and subsystems should be defined and written. Design/ Engineering can also include software program emulation in order to test the implementation of project 'specials'.

5.1.4. Site implementation:

It refers to the site commissioning and is the most extensive phase of the project. Implementation is divided in multiple sub phases: System power up, commissioning safety elements, PLC programming, network health state verified with all nodes online, FSC (Flow System Controller) commissioning, sorter tracking, induction lines commissioning, discharge lines commissioning, and integration with external components and controllers. During implementation it is also executed functionality tests, before the final testing and validation. An earlier testing validation during each sub phase implementation has the added value of troubleshooting isolated problems, making it easier to tackle them and brings more confidence in the implementation process.

5.1.5. Testing and validation:

When all implementation phases are validated a full system test needs to be executed and all requirements described in the beginning of the project need to be validated.

5.1.6. Customer validation:

The customer acceptance is a final system validation where the customer compares the project requirements defined in beginning of the project to the outcome result. When all requirements are valid the customer will take over the system. Although in some cases, an open items list can be created in case of minor unconformities which aren't solved before the agreed deadline.

5.1.7. Support:

It refers to support the customer during the first weeks when the system is in live operation.

5.1.8. Closing project:

All previous phases are closed, project backups and as-build documentation regarding project changes on site are done. Also a mandatory important step to take into account is the lessons learned from all project phases and analyse what can be improved for the upcoming projects.

5.2. Project methodology – Practical implementation:

In this subchapter it will be referred the practical implementation of the project methodology defined previously.

5.2.1. Analysis

As first step before executing project it is important to understand its requirements specifications. It is part of the task to evaluate the electromechanical controls layouts and the system functional specification documentation. It is important to make a critical analysis in order to understand if there isn't any component missing or incorrectly defined. Project 'specials' which deviate from the standard functionalities should be identified and all project risks. If a risk is identified it will be communicated to the project manager and other project team members in other to define plan to tackle it and mitigate it.

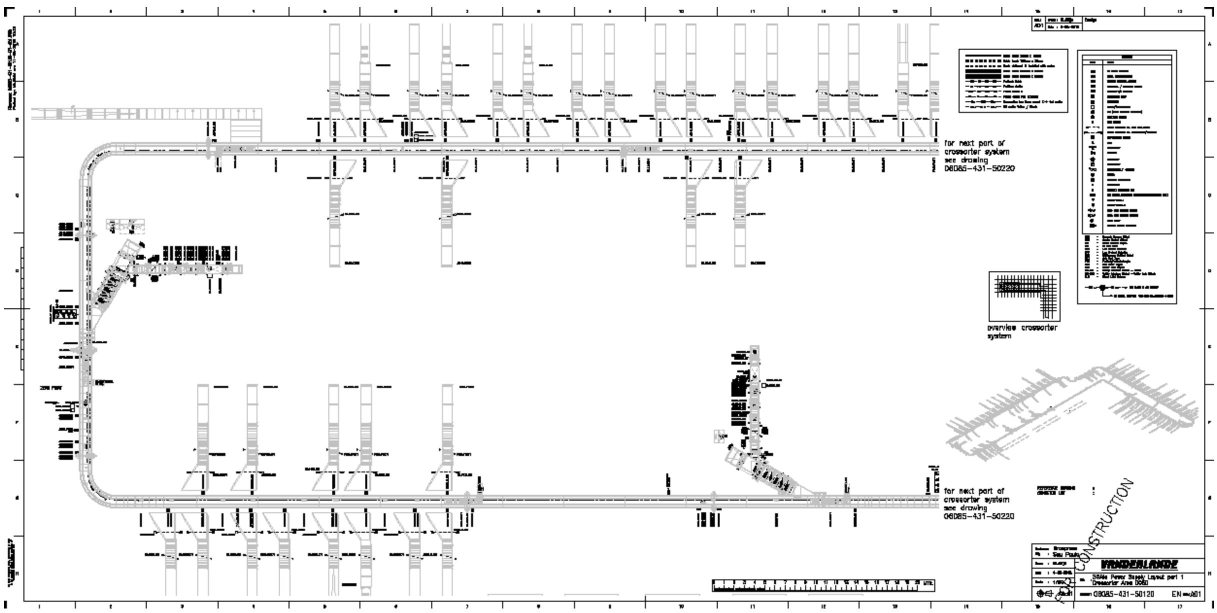


Figure 5-2 Example of an electromechanical controls layout.

5.2.2. Design/ Engineering:

As a first task, the interface documentation between the *Loop sorter* controller (Flow System Controller – FSC) and other external controllers (example: barcode scanner, volume scanner, weighing scale, destination server, external PLCs, etc.) needs to be defined and written. All interface documentation must contain clear and detailed information how the interface should work between the mentioned devices. It should refer the physical location where the interface takes place (example: main controls cabinet), necessary materials for hardware interface (example: Ethernet cable CAT-6, with RJ45 connector), clear message structures defined with examples (if applied), how communications should work and how the different controllers should respond in irregular situations. As a brief practical example of interface specifications which are written: FSC – Barcode Scanner; FSC – Volume Scanner; FSC – Dynamic Weighing Scale; FSC – Barcode – Server Destinations Host.

As a second task, it is important to make the necessary program configuration according to the project specifications. The program configuration can be divided in two groups:

- <u>Safety PLC program</u> – Includes programing all system safety rules and relations regarding power groups, safety events and inputs. The safety PLC configuration also includes the *Loop sorter system* speeds, linear motor definitions, and programing all safety elements such as safety doors and emergency stops;
- <u>Flow System Controller (FSC) program</u> – Refers to program all functional components and relations of the system, including all conveyors sections with all elements present or attach to it (motors; encoders, update sensors, etc). It also includes programming all necessary operative rules (examples: signal lamps and sound alarms) and interfaces specified.

5.2.3. Site implementation:

As a precondition to start commissioning every system is very important that certain steps to be completed previously by the installation team in charge. This team is responsible to install and assemble all mechanical and electromechanical components (conveyors, platforms, safety fences, *Loop sorter*, etc), hardware components (update sensors, emergency stop buttons, etc), electrical cables and cabinets.

The main direct role of the commissioning engineer is to be responsible for bringing the *Cross belt system* operational compiling with the customer requirements. This main task is divided in many subtasks, such as programing and calibrating all different system slaves making sure that all components are performing as they should (light grids, photocells, motor drives, safety emergency stop buttons, etc) and program all system functionalities in the safety PLC and FSC. Beyond previous tasks, the commissioning engineer is also responsible for the integration with other systems (external PLCs, scanners, weighing scales, etc,) and testing all system functionalities.

5.2.3.1. General hardware components and power installation verification

The first tasks that a commissioning engineer has on site is a general mechanical installation overview verification and the electrical power verification in all cabinets.

Regarding the mechanical verification, the commissioning engineer needs to make a general verification that the main mechanical work is finalized accordingly and it will not have negative impact during the commissioning, and if it is not the case, rectifications should be addressed to the installation team with the related priorities. As example of common verifications: system fencing, photocell sensors installed positions, conveyors installed position, system operators push buttons and *Cross belt sorter* works finalized, such as, carrier decks and carriers fully installed.

Concerning the electrical power verification, this task is guided towards a qualified electrical installation person and validated by the commissioning engineer in the end. The following electrical checks is completed in all system power cabinets, including controls cabinets:

- Phase to phase voltage (U-V-W) = 400Vac;
- Phase to neutral voltage (U-N) = 230Vac;
- Phase to ground voltage (U-G) = 230Vac;
- Neutral to Ground voltage (N-G) = 0Vac. The system ground should have been tested prior to this step;
- Controls voltage = between 24-27Vdc;
- Three phase sequence valid – It is verified by analysing the three phase relay analyser installed in the main power cabinet of the *Loop sorter* system.

When a circuit breaker is not in use but it is installed for future system expansion, it must be turned off and a spare indicative label is placed for the future machine owners be aware of it, as indicated in figure 5-3. As examples of power measurements, it can be referred: FSC main controls cabinet; Induct cabinets; interface cabinets (AS-Interface cabinet and PNPN coupler), and power supplies (24Vdc) used to power control devices such as PLC and FSC.

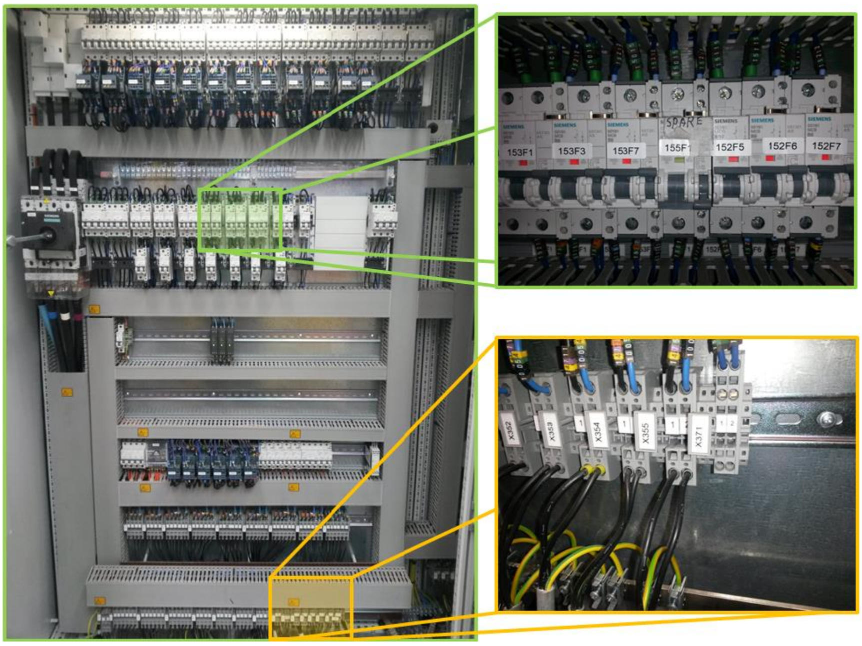


Figure 5-3 *Cross belt sorter m*ain power cabinet.

5.2.3.2. Safety PLC and base hardware elements commissioning:

During this phase, all PROFINET nodes part of the sorter safety PLC will be set online by giving PROFINET node name and IP address: I/O slaves for safety doors, synchronous linear motor drives gateways, safety interface cabinets for induction lines and manual remote control interface cabinet.

Afterwards the site prepared safety PLC program will be downloaded via the Siemens Simatic manager tooling.

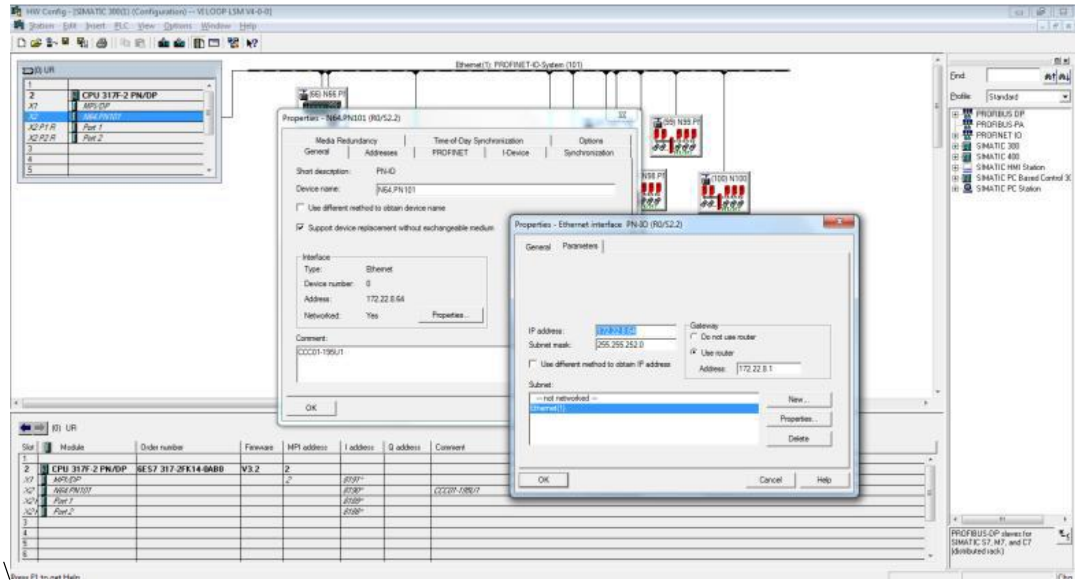


Figure 5-4 Simatic manager Hardware configuration. Setting node names and IP addresses.

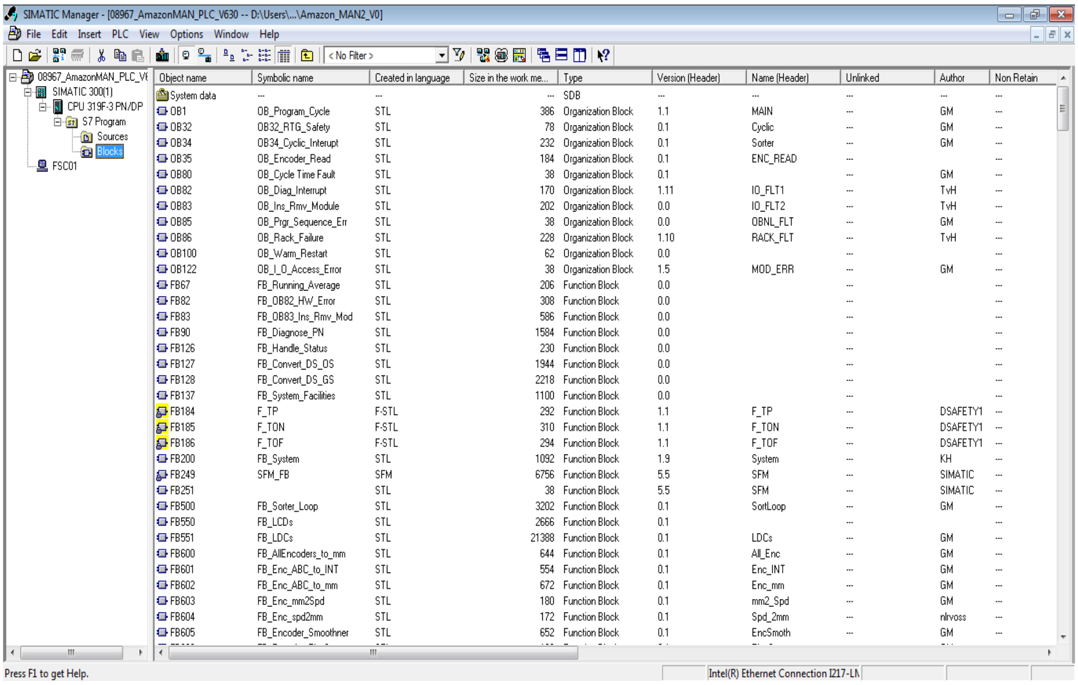


Figure 5-5 Simatic manager function blocks configuration.

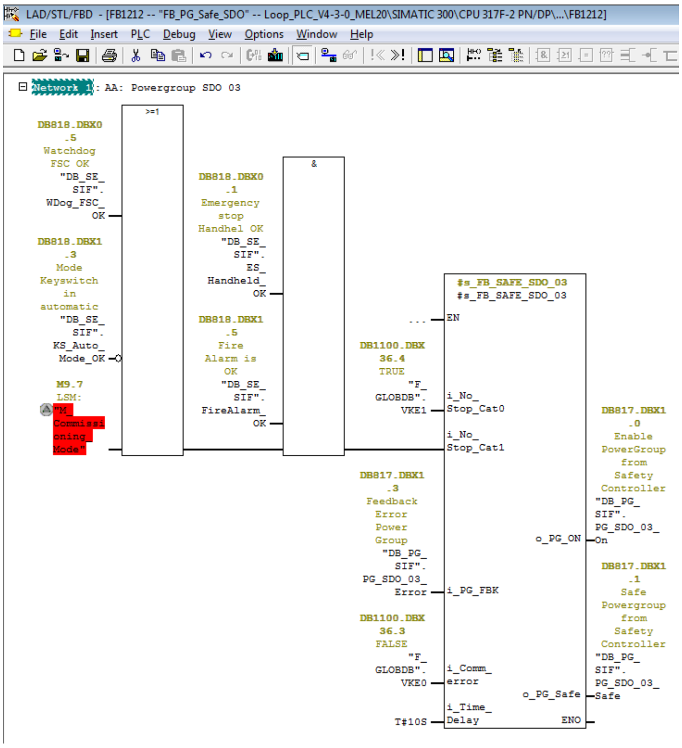


Figure 5-6 Brief example of a safety PLC program configuration.

After downloading PLC program configuration and setting all safety node addresses, the following safety components will be commissioned and tested: safety doors, emergency safety buttons and fire alarm signal. All the safety signals from the mentioned elements need to trigger the stop of the related conveyors power groups.

The functional sorter components are commissioned: Linear motor drives, linear motors, Safety PLC HMI and manual remote control.

<u>Linear Synchronous motor drives and motors</u>

Heathy state of the linear motor drive is verified physically as indicated in figure 5-7; the standard linear motor drive program is downloaded via SEW Movitools software to the drive, verifying once more if the correct IP address and the start-up of the drive is completed with the Movitools software recommendations as indicated in figure 5-8. During the linear motors commissioning it is important to verify that the air gap between the different linear motor units and the carriers' magnet frame is between 3,5mm to 4mm. The distance should not be too close or too distant.

Figure 5-7 SEW linear motor drive.

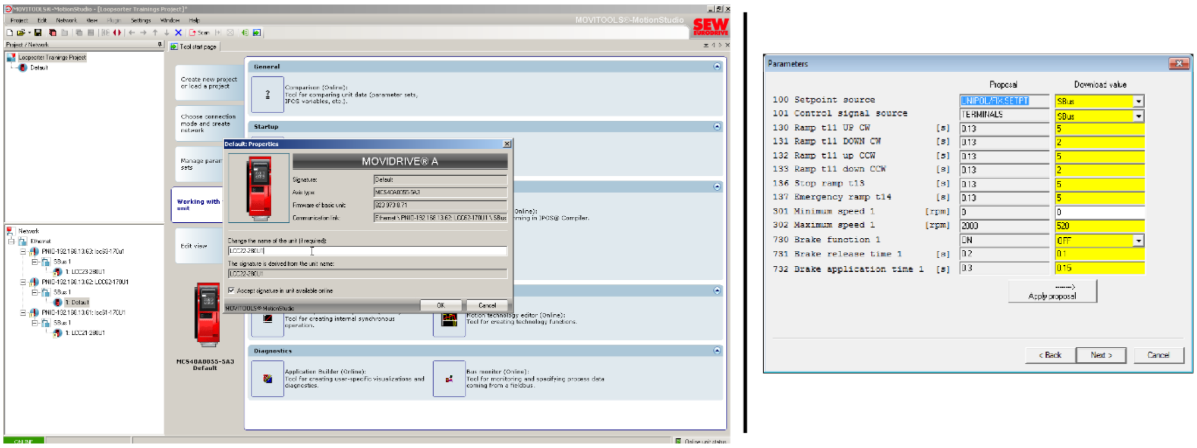


Figure 5-8 SEW Movitools motor drive setup.

<u>Safety PLC HMI</u>

Is commissioned by verifying initially the IP address of this PROFINET node and the alarm list program prepared during the engineering phase is downloaded via Siemens TIA Portal software as indicated in the figure 5-9. After the download is completed the interface push buttons START/ STOP/ RESET are tested and the alarm list displayed in the HMI must be consistent with the real system errors present.

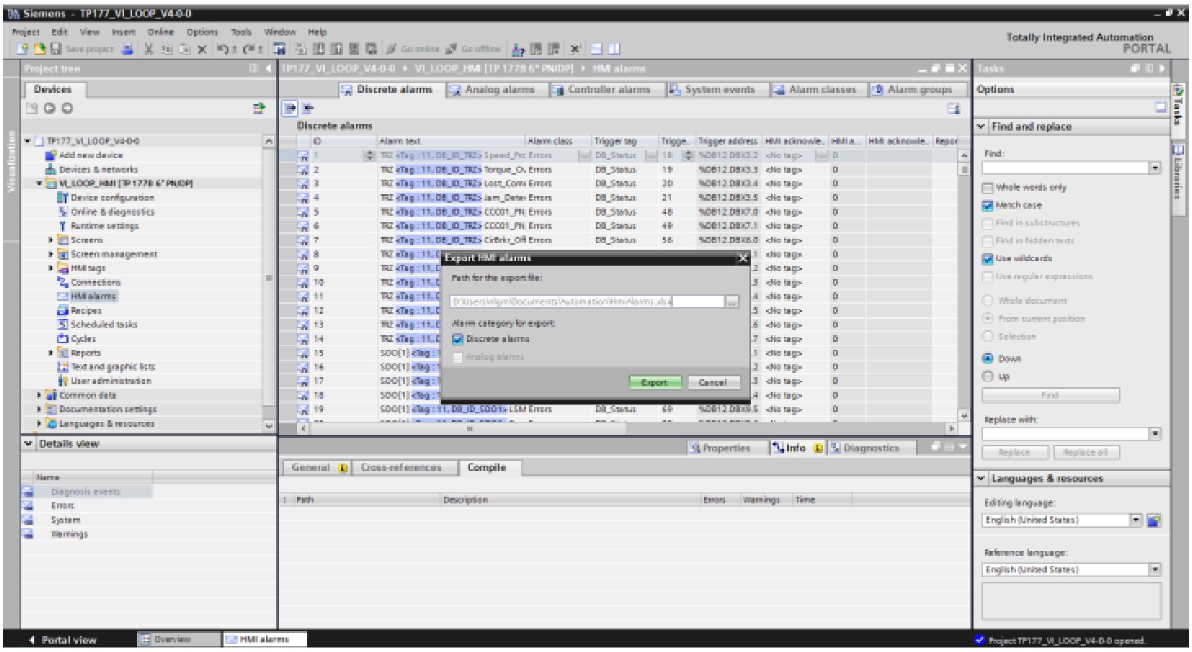


Figure 5-9 TIA Portal with safety PLC alarm list program.

<u>Manual remote controller</u>

Since the antenna controller box which interfaces with the remote controller and the safety PLC interface cabinet was prepared before site by the supplier, it is only necessary to verify if the push buttons START/ STOP/ RESET/ E-STOP are operating correctly and the system manual speeds have the product specification.

Figure 5-10 Manual remote controller.

After the previous steps the *Loop sorter* should be ready to make the first spins. However, the first system laps are executed with care by using the manual remote controller in order to observe if there are any electromechanical faults, which could be noticed by uncommon noise or vibrations.

During this period the mechanical installation supervisor fine tunes the carrier chain tension of the *Loop sorter*. If the carrier tension is too high or too low, unnecessary and harmful vibration can be caused by the carriers guiding wheels due to a rough rotation movement on the sorter track curves. If the system operates for long period with high vibration it can damage carrier wheels, bearings, and even the sorter track.

Another important verification which is executed at this stage, it is regarding the linear synchronous motors, analyze their torque direction and if there are any odd noises. This can be done by being next to a linear motor when the *Loop sorter* is stopped initially, afterwards a relatively high speed should be set. If the linear motor starts pulling the *Loop sorter* in the correct direction without any odd noise and vibration, everything should be fine. If there are odd noises and high vibration the linear motor could be breaking the system instead of pulling it or could even an electrical fault. The linear motor should be checked for its anomaly. This test is performed on every single linear motor group.

5.2.3.3. Flow System Controller (FSC)

After verifying that the *Loop Sorter* is running stable with the safety PLC, the most complex commissioning steps start with the FSC commissioning.

5.2.3.3.1. Full PROFINET network commissioning

At first all network devices need to be online and configured with the correct PROFINET address and I/O cycle update time: Network switches, all I/O slaves (for photocell sensors, induction line cabinets, signal light columns, etc) and gateway devices (AS-I gateway, PNPN coupler). It is executed in the same way as mentioned earlier via the safety PLC slaves by using the Siemens Simatic manager software. Slaves that support real time system functions, such as encoder pulses, update sensors, motor drives gateways, need to have a very short I/O cycle time update (2-4ms). On another hand, devices which interface with non-real time system functions can be set to a higher I/O cycle time update (100-500ms, depending on the slave), for example, signal lights and sound warnings.

Regarding the PROFINET network important verifications are executed:

- All PROFINET slaves should be verified, making sure that all nodes are connected to the correct network switch ports, especially the connections between network switch to network switch. In order to have PROFINET ring topology working correctly it is imperative that the ring manager and network switches clients have the correct communication ports assigned. The PROFINET connections and topology is verified by using the Siemens PRONETA application;
- As confirmation of the network stability a ping test is done by changing temporarily the main network switch connection as indicated in the figure 5-6. The cable connected to port 1 of the main network switch should be connected to the commissioning laptop. If the connection was done properly the commissioning laptop and the main network switch are connected on the extreme sides of a line network. A time based ping command with specified number of bytes can be set from the commissioning laptop to the main network switch (ping '*device ip*' –l '*number of bytes'* –t). If during 5 to 10 minutes the reply delay from the main network switch is not higher than 4 ms for 1024 bytes the network should be healthy, otherwise there is a fault in the network, which needs to be addressed.

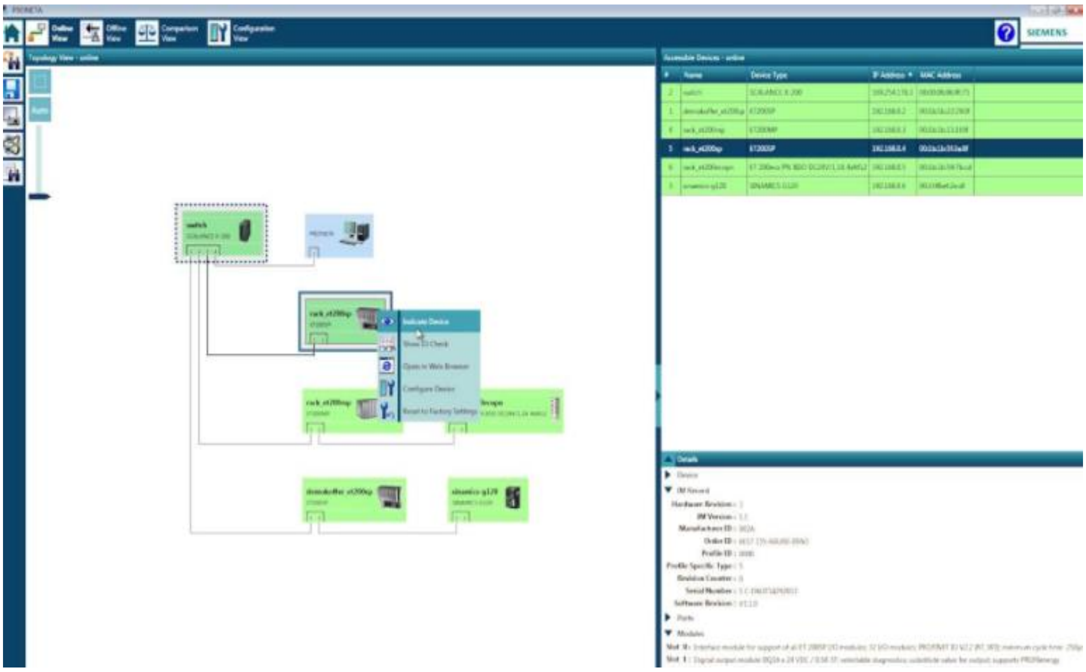


Figure 5-11 Siemens PRONETA software.

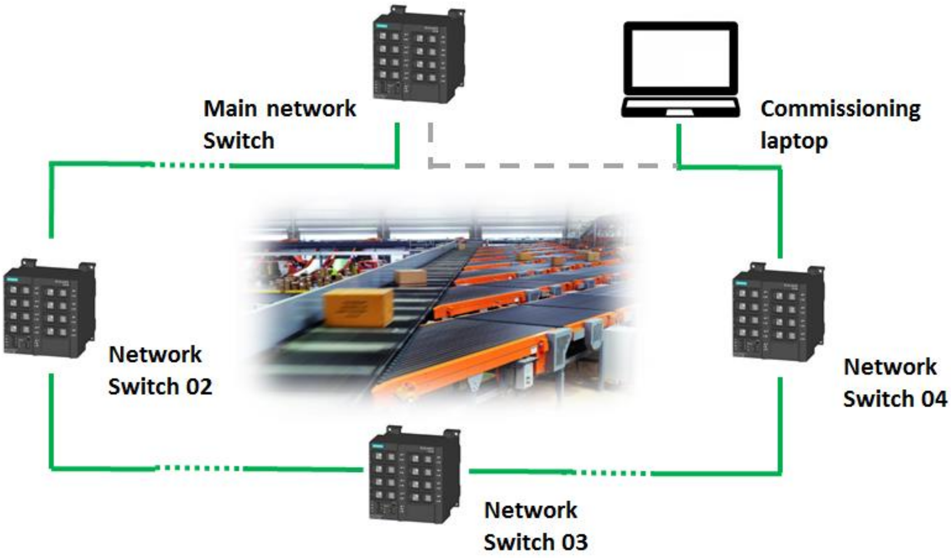


Figure 5-12 Network health check setup.

Furthermore, the PROFINET ring topology network needs to be configured via the Simens Simatic manager software. The ring topology has redundancy as advantage compared to the normal line or tree network topologies. If there is a faulty cable on the network, the ring manager will split automatically the ring network into two line networks. To set up the PROFINET ring topology it is necessary to define a network switch as ring manager, network switches connected to the ring as clients and the ring ports that the manager and clients are connected on the ring topology.

5.2.3.3.2. *Loop sorter* tracking:

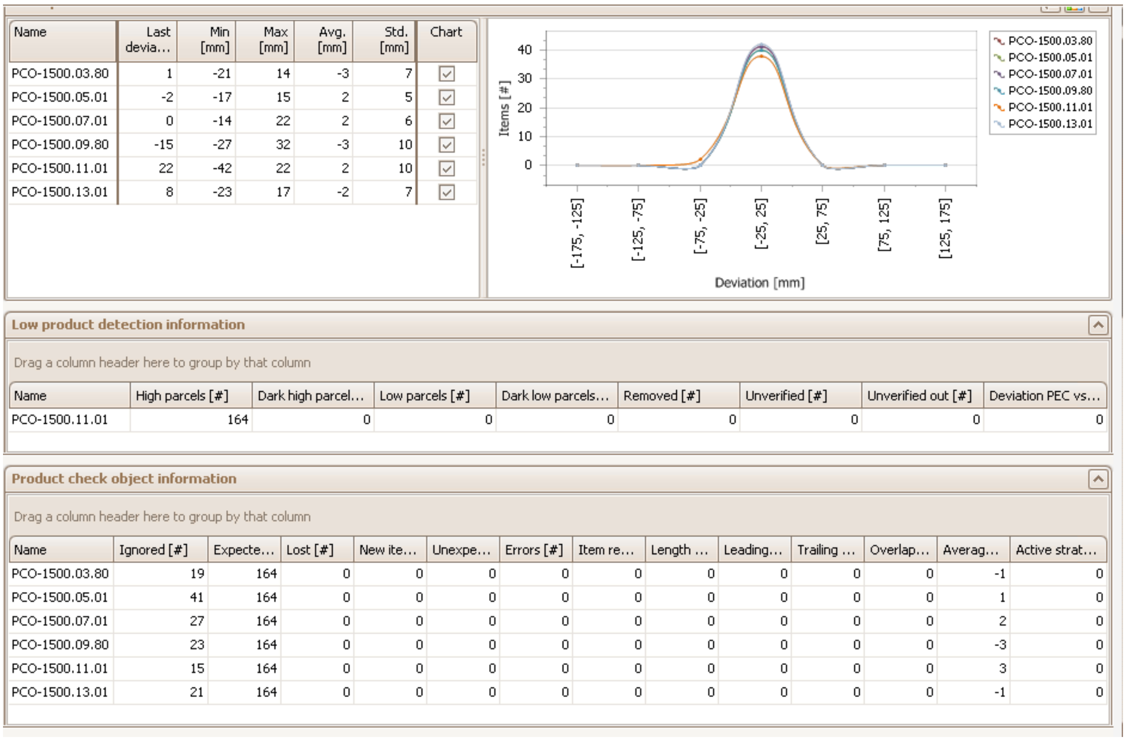
After the PROFINET network stability being assured the *Loop sorter* tracking needs to be implemented. The *Loop sorter* tracking can be dived in two stages, carrier tracking and product tracking.

Carrier tracking

It relates to the tracking of each carrier. The system knows where every single carrier is at any moment of time when implemented. In order to commission it, inductive proximity switches are adjusted mechanically as first step in order to detect the first carrier and the all other carriers. The distance between different proximity switches is calculated via software and adjusted according to the commissioning engineer expertise, by fine tuning the software program position for each carrier proximity switch.

Product tracking

It relates to the tracking of each item. The *Loop sorter* controller knows the exact position of every single item at any moment of time on the sorter, being able to update and correct it whenever is necessary. The product tracking implementation is executed by initially adjusting all photocell sensors installed over the *Cross belt sorter*, on the perpendicular direction of the movement of the sorter. Relating to the cross belts position the photocell sensors should not be positioned extremely high since they need to detect items with 10mm minimum height and cannot be too low since the sorter decks can create false photocell triggers, which could lead to system errors. After completing photocells mechanical adjustments square shaped items are placed manually on strategic positions on different carrier decks. Afterwards the FSC software is used to calculate the correct software position to be configured in the program configuration. After finalizing the software calculation, in order to verify the correct photocell sensors positions in the software program around 20 squared items are placed manually over the sorter decks and it will the sorter should run for 10 rounds. The FSC diagnostics software will make a real time chart regarding the item tracking data, it compares the real time item tracking with the software calculated data. The average calculated deviation should not be higher than 25mm.



Name	Last devia...	Min [mm]	Max [mm]	Avg. [mm]	Std. [mm]	Chart
PCO-1500.03.80	1	-21	14	-3	7	☑
PCO-1500.05.01	-2	-17	15	2	5	☑
PCO-1500.07.01	0	-14	22	2	6	☑
PCO-1500.09.80	-15	-27	32	-3	10	☑
PCO-1500.11.01	22	-42	22	2	10	☑
PCO-1500.13.01	8	-23	17	-2	7	☑

Name	High parcels [#]	Dark high parcel...	Low parcels [#]	Dark low parcels...	Removed [#]	Unverified [#]	Unverified out [#]	Deviation PEC vs...
PCO-1500.11.01	164	0	0	0	0	0	0	0

Name	Ignored [#]	Expecte...	Lost [#]	New ite...	Unexpe...	Errors [#]	Item re...	Length ...	Leading...	Trailing ...	Overlap...	Averag...	Active strat...
PCO-1500.03.80	19	164	0	0	0	0	0	0	0	0	0	-1	0
PCO-1500.05.01	41	164	0	0	0	0	0	0	0	0	0	1	0
PCO-1500.07.01	27	164	0	0	0	0	0	0	0	0	0	2	0
PCO-1500.09.80	23	164	0	0	0	0	0	0	0	0	0	-3	0
PCO-1500.11.01	15	164	0	0	0	0	0	0	0	0	0	3	0
PCO-1500.13.01	21	164	0	0	0	0	0	0	0	0	0	-1	0

Figure 5-13 FSC item tracking data.

5.2.3.3.3. Rail power commissioning

In order to each carrier perform actions (induct and discharge) they need to be powered all the time. The power is collected by the *Loop sorter* carriers via several rail power connections distributed along the sorter. The rail power connections power a serial cable line which every single carrier is connected in parallel.

The rail power commissioning consists in the rail power voltage verification and eventual necessary voltage adjustments. The rail power verification is assured by measuring the voltage and ground on the most distant position and an intermediate points related to the rail power cabinet connection to the rail, the correct measured value should be 80Vdc. On large systems, the rail power can be powered by two or more power cabinets, in order to power all carriers. In case of multiple rail power cabinets the rail voltage and ground should be measured by having a single cabinet switched 'ON' at the time, in order to verify that all power cabinets are working accordingly.

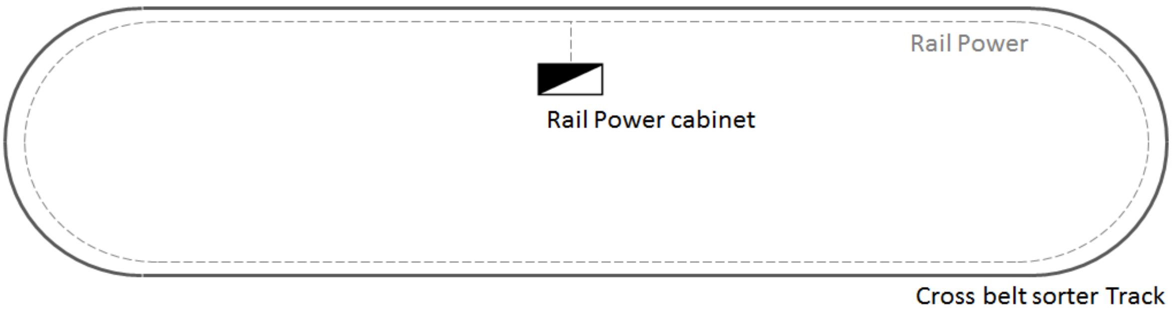


Figure 5-14 Sorter rail power simplified schematic and its power cabinet.

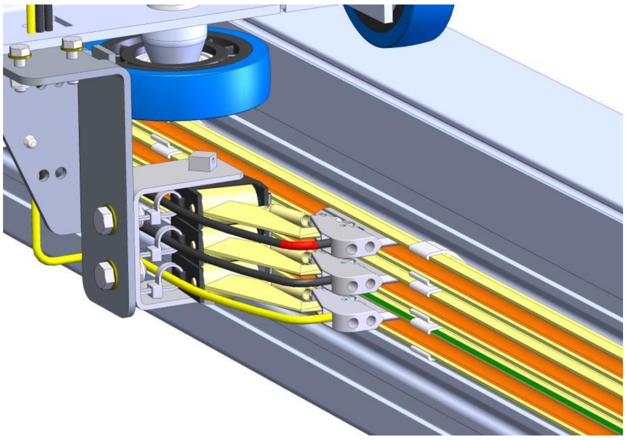


Figure 5-15 Sorter rail power connection.

5.2.3.3.4. Maintenance zone commissioning

The maintenance zone as the name indicates is a zone allocated on the *Loop sorter* and has the function to allow maintenance actions on different system components:

- Carriers – is able to perform running tests on a single carrier or multiple. This allows to test each carrier controller and the mechanical components of the carrier. It is also possible to download and upgrade the software of the carrier controller;
- Light grids – is able to download light grids controller software and set the correct settings so the objects can be detected accurately;
- Carrier action unit – It allows to download and update its software and has the possibility to perform tests;
- Low item update sensor cameras – It has the possibility to configure camera settings so the objects can be detected accurately;
- Linear motors – It has the possibility to disable linear motor drives, in case one is malfunctioning.

In order to commission the maintenance zone as a first step is to define the exact position related to the '0'point of the sorter of the maintenance carrier action controller unit which defines the maintenance position. When the maintenance position is defined it is necessary to install and upgrade the maintenance console with the necessary software for the different sorter components mentioned earlier, via USB windows image.

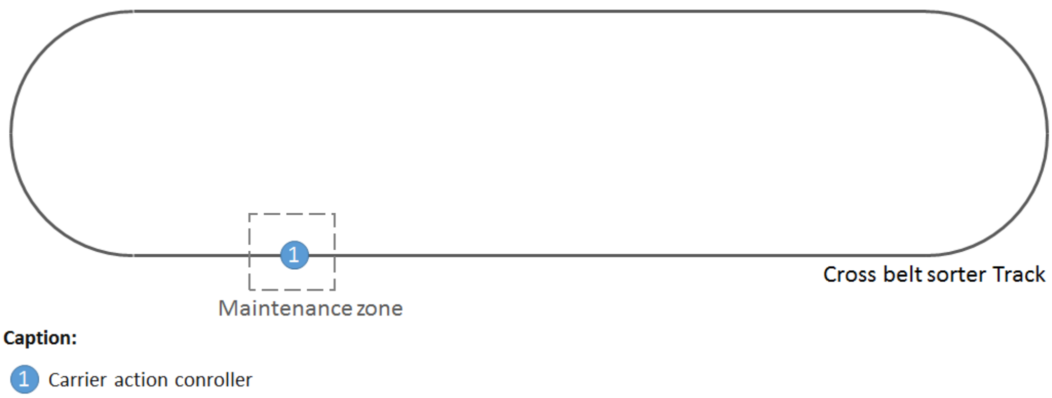


Figure 5-16 Maintenance zone.

5.2.3.3.5. Carriers

Commissioning *Loop sorter* carriers refers on making sure that every single carrier is working according to its specification, so being able to run its cross belt on different directions and speeds, without any mechanical or electrical failures. However, before performing the carriers running test, each single carrier controller is upgraded to the latest software.

5.2.3.3.6. Carrier action units

Carrier action units as the name indicates have the function to request carrier actions through communication with the carrier controllers via infrared. Carrier action units are distributed along the *Loop sorter* track close to discharge lines and induction lines positions. The commissioning of each carrier action controller is completed by assigning an IP address and node name to each single controller. It is also necessary to download the correct software to the controller, in order to work according to its specifications. At last, is necessary to calculate and program the exact position on the *Loop sorter* main controller so it can perform discharge and induct actions. This calculation is done by using FSC diagnostic software and requires position fine tune when inducing and discharging.

5.2.3.3.7. Conveyor sections with item tracking

In order to commission a single conveyor section properly it is necessary to understand different conveyor elements and characteristics:

- Type of conveyor (roller or belt) – Depending on the conveyor type, objects conveyed will have different behaviour. In the case of a metal roller conveyor it can be expected that items will slip easier during start and stop conveyor actions compared to a belt conveyor. Also within the belt conveyor range there are belts with higher and lower grip. In simple terms, on high the grip conveyor belts, lower gaps can be implemented between items and the conveyor can have higher speeds, higher acceleration and deceleration characteristics. With this information we can conclude that high grip on the transport surface of a conveyor is more suitable for high capacity conveyor lines;
- Type of motor and motor drive – It is important to take into consideration the motor and motor drive characteristics so it can be programmed according to its specifications and have a better use of their performance;

- Encoder – If there is an encoder attached to the transportation line, having an understanding about its error margin, will facilitate the fine tuning of the encoder resolution to the real transport section speed in the software and consequently improve item tracking;
- Sensor(s) update type and position – The sensor update type can dictate how well an item can be detected. Generally light grid barriers can be used in between conveyors and have the advantage of being able to detect very low items. Normal photocell sensor updates have the disadvantage that they cannot detect very low items;
- Type of items – The type of items dictates being conveyed affect how well tracking can be implement. For example, if the system is going to operate with challenging items, such as, products involved in flexible plastic bags, the item tracking will be more challenging compared to a standard cartoon box. This happens because the item shape and dimensions can change along its transport over the different conveyor lines;
- Upstream and downstream sections characteristics – The upstream and downstream lines are important to take into consideration for gap control and for tracking handover from one section to another. For example, if the upstream conveyor is running on a lower speed compared to the conveyor in analysis, it can be expected that there is a tracking delay due to the speed difference between conveyors on the item transition from one conveyor to another.

Regarding practical approach for tracking implementation, the following conveyor characteristics need to found for every single conveyor:

- A precise length measurement of the conveyor transport section needs to be programmed in FSC;
- The conveyor speed read by FSC needs matches the real speed of the conveyor, so the encoder resolution needs to be adjusted in the program software accordingly;
- Speed, acceleration and deceleration motor drive settings need to match the programed parameters in the FSC program software;
- The update sensor position needs in FSC to match the real conveyor position.

When all the characteristics are determined, the following test should be done when the system is running in automatic mode:

T1. Place an item on the conveyor and let it pass through a first sensor update and it should to stop in dieback[1] on end of the same section, before the next sensor update. If the first update sensor is located in between conveyors the item should be placed manually on the upstream conveyor instead. The figure 5-17 represents described test for sensor updates positioned in between conveyors;

T2. Check the item transport dimensions and the position calculated by the FSC controller. The comparison between the real values (item length and stopped position) should be similar with a small deviation allowed. In most of the cases a deviation not higher than 25mm, but it depends on the conveyor type, speeds and encoder resolution and error margin.

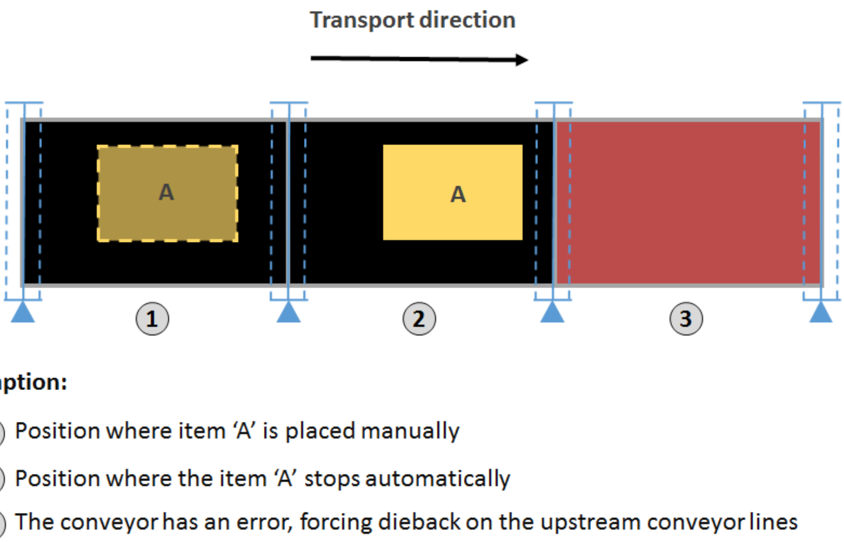


Figure 5-17 Item tracking test.

5.2.3.3.8. <u>Induction lines commissioning</u>

Commissioning inducts is one of the most complex processes in the *Loop sorter* system and the commissioning steps are executed as it follows:

- Light grid barrier commissioning;
- Motor drives setup;
- I/O check from all the node slaves;
- Program configuration fine tuning;
- Testing.

[1] Dieback – Refers when the actual conveyor section is stopped due to the stop of the downstream conveyor sections. The downstream conveyor sections stop can be caused due to item congestion waiting for being resolved, a blockage error or any other fault that can cause the downstream sections to stop.

Light grid barrier commissioning

The light grid sensor is commissioned in three steps. First it needs to be mechanically adjusted so that the LED beams can see through the conveyor sections. At second step the ligh grid latest software is downloaded to its embedded controller via the maintenance console installed previously and its settings are adjusted: minimum item dimensions and encoder detection speed.

Figure 5-18 Light grid barrier and its embedded controller.

Motor drives setup

Initially before setting up the motor drives the motor plates information is registered and the setup of the drive is proceeded with the SEW Movitools software. As a practical example, an induct line has 9 motors and each motor is commissioned individually. Each motor plate ID is inserted in the software in order to retrieve firstly the recommended motor drive settings for the related motor and the initial start-up is completed. As a second step, the motor maximum speed settings for the motor are found by checking at the same time the conveyor belt speed with the help of a tachometer and via the motor manual mode. Afterwards, with the maximum speed defined the acceleration and deceleration parameters are calculated via a spreadsheet which relates with the maximum motor speed for the SEW motors in question. The same steps are followed for all other motor drives present in the induction line.

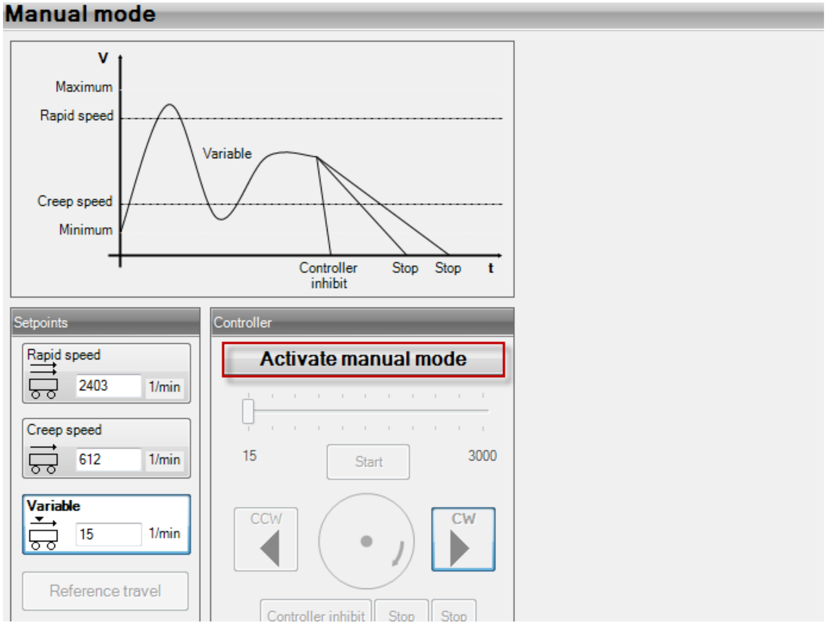


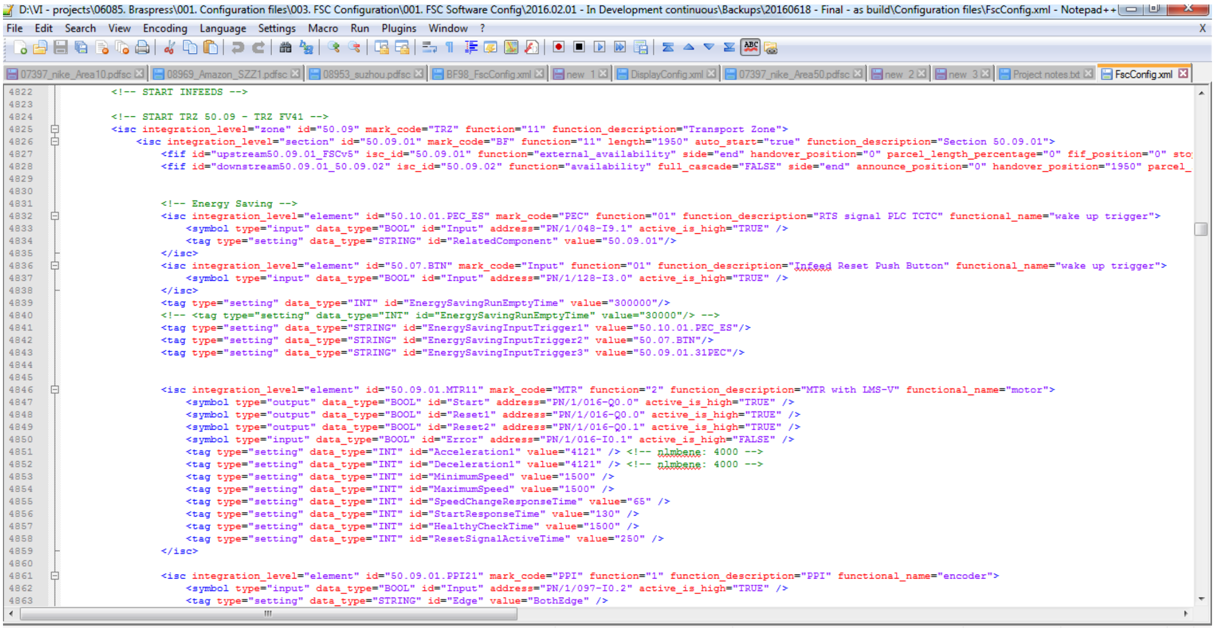
Figura 5-19 SEW movitools settings in manual mode.

I/O check from all the node slaves

At this stage all I/O signals related in the infeeds are verified with the FSC diagnostic tooling, this includes photocell sensors, light grid barrier signals, encoder signals for conveyor speed detection, functional push buttons to reset and signal light columns.

Program configuration fine tuning with testing

In order to make sure that the induction line is working properly it is necessary to review and adjust all settings which were prepared during the engineering phase of the project. The settings which require adjustments are the conveyor lengths, position of the photocell sensors on the conveyors, encoder resolution per conveyor and motor settings. The induct profile on each carrier is adjusted and fine-tuned with testing.



Figur3 5-20 FSC program configuration.

Testing

Normal item flow:

T1. Item is placed manually on the most left side of the induct;

T2. Item is placed manually on the most right side of the induct;

T3. The largest item type possible that the induct should handle is placed on the induct line.

R. For all tests, the items should be inducted on the middle of the expected carrier(s). It is normal that this process can take couple of tries on fine tuning till the prefect result is reached.

Dieback scenario

The dieback scenario refers when an item is placed manually on the induct and it waits stopped on the most downstream possible position for an available carrier. As a second stage of the test a carrier must be available after certain period of time allowing the item to be inducted from its stop position to the expected carrier.

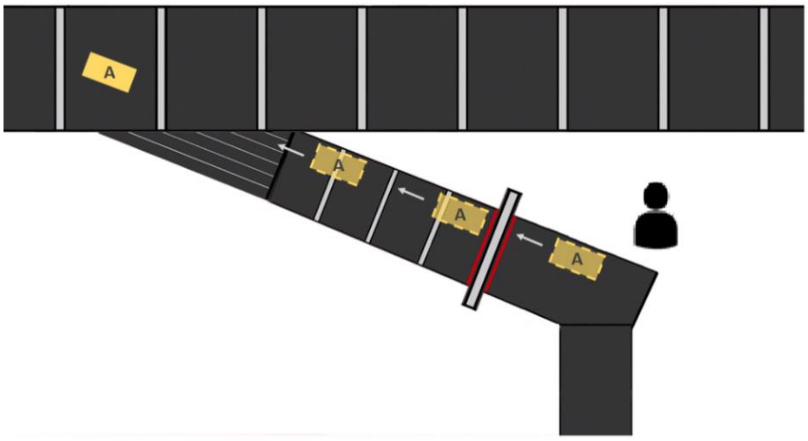


Figure 5-21 Induction line profile test representation.

5.2.3.3.9. Discharge lines commissioning

The commissioning of a discharge line depends on its mechanical design, type of items being conveyed and the intended sortation capacity. Regarding discharge lines types, it can be divided mainly in three general mechanical categories: Direct chute, gravity chute and conveyor section.

Direct chute

Has the base principle of gravity, meaning when a cross belt carrier performs a discharge action the item will slip through a small metallic plate (or other material) and end up inside a bag, tote or some designed container. In some cases there is no metallic slipping plate, meaning that the item goes directly to the container. The direct chute type is more suitable for small and light weight items and have the advantage of being quite compact meaning that is makes a better use of the available *Loop sorter* space.

Figure 5-22 Direct chutes.

Gravity chute

Has the same base working principle of the direct chute, but when the item is discharged, it slips longer through a metal place or non-driven rollers. In the gravity chute category it is possible to find the spiral chute design and in some cases there are mechanical pneumatic breaks to decelerate items when sorting due to their relatively high weight. This type of chute is used mostly within systems that have large and heavy items.

Figure 5-23 Spiral gravity chute.

Conveyor section

The discharge to a conveyor section is very common in the cases that items still need to pass through a posterior sorting process via other downstream system or the operators working position is relatively distant from the sorter.

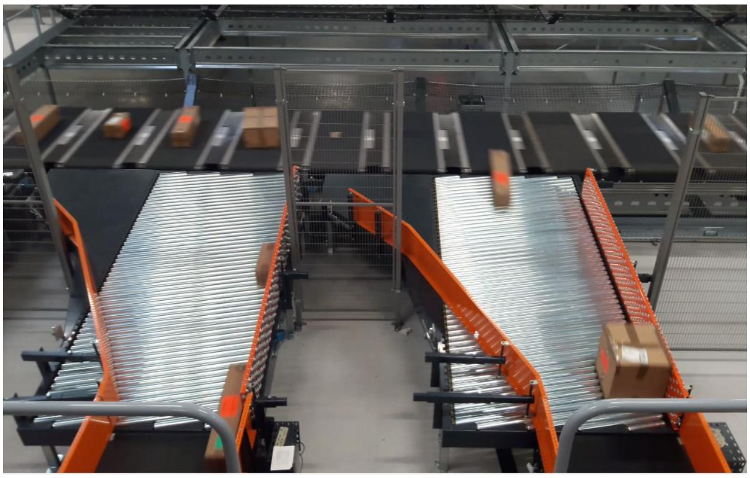


Figure 5-24 Conveyor sections at discharge position.

Regarding the commissioning process, besides the regular I/O check and interface signals, the following discharge profile settings are programed in FSC and tested:

- Discharge position;
- Cross belt discharge speed;
- Cross belt discharge acceleration.

The ideal sort profile is defined with the best combination possible of the previous settings, but it will always differ slightly from the items characteristics (dimensions and weight), discharge line and sorter speed. In order to define the ideal sort profile settings, several tests are performed with the average item type and the largest and heaviest item possible. The tests should also be performed with the possible sorter speeds, in case there is more than one.

As general knowledge, direct chutes require higher discharge speed and acceleration compared to a gravity chute, since they are more compact and the discharge window available to fit an item is smaller. Gravity chutes, most of the times require a slower sort speed and acceleration since heavy items can clash on high speeds when stopping at the bottom position of the chute. The sortation to a conveyor section is also performed more gently compared to the direct chutes, since items still need to be conveyed and correct item gapping needs to be maintained. On the discharge to a conveyor section generally is programed a limited discharge actions that can happen consecutively, as example, an item can be discharged every four carriers.

As a practical example of a direct chute, the acceleration and discharge speed are set to 3000mm/s^2 and 3000m/s, it works the best for light and medium to heavy items based on experience and multiple sites commissioned. The discharge position is found for every single chute by testing and fine-tuning.

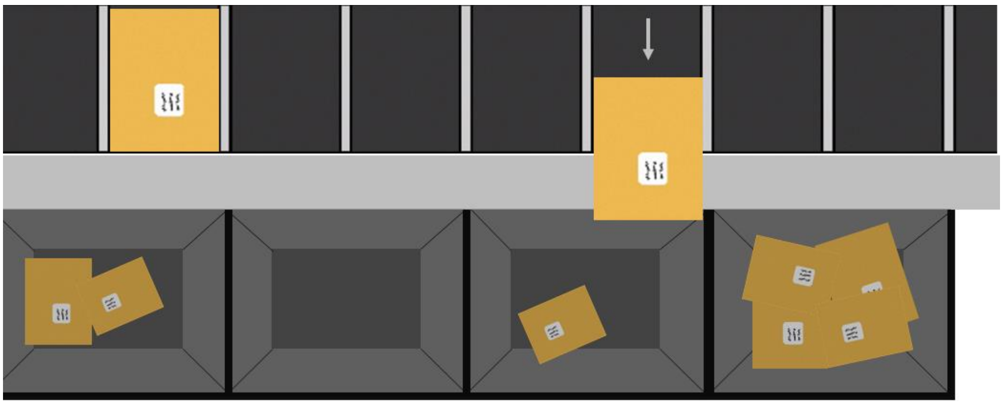


Figure 5-25 Sorting to direct chute.

5.2.3.3.10. Barcode Scanner tunnel interfacing

The commissioning of the interface of a barcode scanner is divided in:

- Hardware interface;
- Communication interface;
- Testing.

On a first phase the scanner supplier needs to assemble and set up mechanically all the scanner components. When the scanner is in place three hardware interface elements are verified: PROFINET cable or Ethernet cable, speed sensor device (optocoupler) and a hardware trigger signal which can be from a real photocell sensor update or hardware 24Vdc signal sent based on item tracking position.

When the hardware interface is complete, the communication is tested and needs to be in accordance with the interface documentation defined for the system: communication channels, keep alive messages, hearth beat message, request message to read item and reply message with the barcode(s) result(s).

Practical example

As hardware functionality FSC sends a 24Vdc with the dimensions of the item (as if it was a photocell sensor) when the front of the item reaches 1000 mm before the head of the frame of the scanner. The request message is sent 50 mm after the beginning of the hardware trigger.

Regarding the message structure, bellow it is shown a practical example of messages structures exchanged between FSC and the barcode scanner controller.

FSC to Scanner → read request

<stx>id1|ppppp|<checksum><etx><cr>

<stx>10|05045|<checksum><etx><cr>

Scanner to FSC → read result

<stx>id2|ppppp|tbbbb<label>;<label>|<Scanner state>|<checksum><etx><cr>

<stx>12|05045|6 0020PBOX828006800100|1|<checksum><etx><cr>

Field	Definition
id1	Request message identifier (10)
id2	Result message identifier (12)
ppppp	Item unique identification code. Exemple: 05045
t	Scanner data state: No read (5), Good read(6), Too many labels (7)
bbbb	Number of characters. Example: 0020
<label>	Barcode label. Example: PBOX828006800100
;	Field separator, when more than one label is read
<Scanner state>	Scanner state: Scanner ok (1), scanner in Error (3)

Table 5-2 Message structures definitions.

<u>Barcode scanner read rate performance tests</u>

Regarding testing, it happens in two phases: barcode scanner read rate performance tests and exceptional test scenarios tests. The tests need to be performed with the smallest barcode label type that the system will use in the future. Different barcode types must be tested in case if applicable.

<u>General read rate verification</u>

T1: Place ten square shaped average size items with a single readable barcode label manually on the middle of ten different carriers. Let the sorter run ten rounds.

R1: The expected result should be 100% read rate with the correct barcode assignment to each item, in case is not, a reasonable reason should justify the read rate failures.

<u>Barcode label on item extreme surface positions</u>

T2: Labels should be placed on the most extreme position of different items as indicated on figure 5-26, in order to make sure that the scanner is reads on the most extreme positions of each item. This test can be executed at the same time of the surface tests.

R2: The expected result should be 100% read rate with the correct barcode assignment to each item.

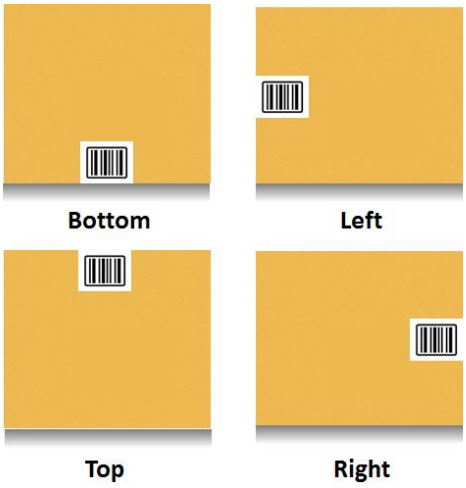


Figure 5-26 Barcode label on item extreme surface positions.

<u>Item top surface scan stress test:</u>

T3: In order to stress the barcode scanner the most extreme positions should be tested in a short distance. This has the impact that the scanner needs to be able to focus in a very small period of time and read the barcode from each single item.

In order to stress the top scanner unit the lowest and highest item types must be placed in interleave sequence with a single barcode on the top surface and the items should be closer to each other, around 60mm. The figure 5-27 describes how it should be positioned.

R3: The expected result should be 100% read rate with the correct barcode assignment to each item, in case is not, a reasonable reason should justify the read rate failures.

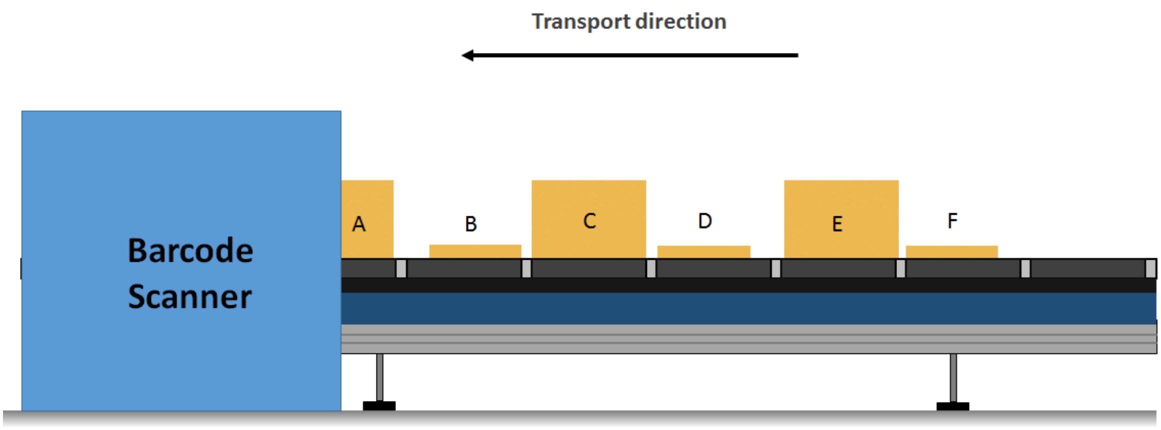


Figura 5-27 Item top surface scan stress test.

Item lateral surface scan stress test:

T4: In order to stress the lateral scanner units the items must be positioned on extreme positions in interleave sequence with a single barcode for one side scan unit and the items should be closer to each other, around 60mm. The figure 5-28 describes how it should be positioned. This test should be executed for each scanner lateral side available (left and right).

R4: The expected result should be 100% read rate with the correct barcode assignment to each item, in case is not, a reasonable reason should justify the read rate failures

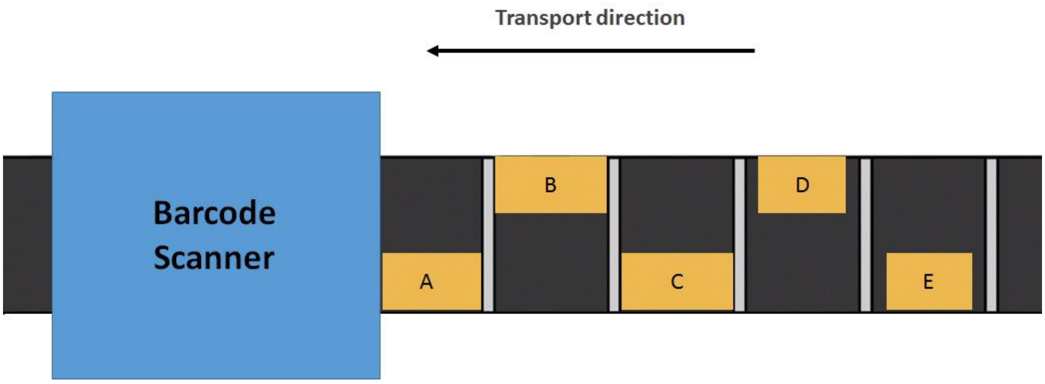


Figure 5-28 Item lateral surface scan stress test.

Exceptional tests scenarios

On the exceptional scenarios, it includes testing the all specified exceptional functionalities including error codes:

- The barcode scanner should be able to read up to a specified number of barcode labels. This means if an item with more labels than specified an error code should be received from barcode scanner for this same item;
- Other common test is the scanner internal error codes test. If a scanner unit has a fault a certain error code should be sent to FSC.

5.2.3.3.11. Volume scanner interfacing

The commissioning interface of a volume scanner is divided in:

- Hardware interface;
- Communication interface;
- Testing.

The hardware interface generally is similar or identical to the barcode scanner interface, so the same requirements are applied: PROFINET or Ethernet cable, speed sensor device and a hardware trigger signal. The communication is also similar to the barcode scanner tunnel and it needs to follow the defined system specification: communication channels, keep alive messages, hearth beat message, request message to read item and reply message with the barcode result. Compared to the barcode scanner tunnel, the volume scanner interface is expected to have different message structure, since the data handled is also different.

<u>Practical Example</u>

As hardware functionality FSC sends a 24Vdc with the dimensions of the item (as if it was a photocell sensor) when the front of the item reaches 1000 mm before the head of the frame of the scanner. The request message is sent 50 mm after the beginning of the hardware trigger.

Bellow it is shown a practical example of messages structures exchanged between FSC and the volume scanner controller.

FSC to Scanner → read request

<stx>id1|ppppp|<checksum><etx><cr>

<stx>10|00095|<checksum><etx><cr>

Scanner to FSC → read result

<stx>id2|ppppp|t llllwwwwvvvv|ooo|<Scanner state>|<checksum><etx><cr>

<stx>12|00095|6 0100020004500009|85|<checksum><etx><cr>

Field	Definition
id1	Request message identifier (10)
id2	Result message identifier (12)
ppppp	Item unique identification code. Exemple: 00095
t	Scanner data state: No read (5), Good read(6), Too many labels (7)
llll	4 characters with Length in mm. Example: 0100
wwww	4 characters with Length in mm Example: 0200
hhhh	4 characters with Length in mm Example: 0450
vvvv	4 characters with Length in dm^3. Example: 0009

ooo	3 characters with item orientation, between -90 to 90 degrees
<Scanner state>	Scanner state: Scanner ok (1), scanner in Error (3)

Table 5-3 Message structures definitions.

Volume scanner read rate performance tests

Regarding the testing, it has less steps compared to the barcode scanner but it still requires two group of tests: volume scanner read rate performance tests and exceptional test scenarios.

General read rate verification:

T1: Place ten square shaped average size items with average dimensions (for the related system) on the middle of ten different carriers. Let the sorter run ten rounds.

R1: The expected result should be 100% read rate with dimension results within the specified error margins. On every round each item should have comparable dimension results from the previous rounds.

General read rate verification:

T2: Place ten different items, from the smallest to the biggest possible that the volume scanner is specified to measure. Items should also be placed in a strategic position on the carriers: most extreme positions of the carriers should be used, items very close to each other and on a rotated position on the sorter. The figure 5-29 describes an example how items should be positioned.

R2: The expected result should be 100% read rate with dimension results within the specified error margins. On every round each item should have comparable dimension results from the previous rounds.

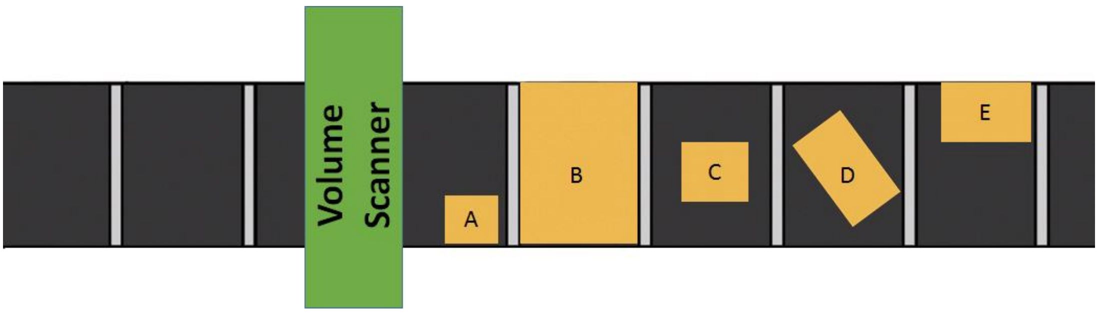


Figura 5-29 Volume scanner read rate performance tests.

Exceptional test scenarios

Exceptional scenarios, include testing the all exceptional functionalities including error codes:

- The error codes, for item over and under dimensions should be tested;
- All other specified errors codes that the volume scanner is also not able to measure the item, such as, 'out of range' when the item is laying slightly out of the carrier.

5.2.3.3.12. Weighing scale interfacing

The commissioning of the weighing scale interface is divided in:

- Hardware interface;
- Communication interface;
- Testing.

On a first phase the weighing scale must be verified mechanically by the weighing scale supplier, making the necessary adjustments. When the weighing scale is in place two electrical hardware interface components need to be verified: PROFINET or Ethernet cable and hardware trigger signal which can be from a real photocell sensor update or hardware 24Vdc signal sent based on item tracking position. In some cases the weighing scale also has extra hardwire interface with FSC and needs to be verified, as example, hardwire error signal for severe faults, main power feedback and weighing scale encoder.

When the hardware interface is complete, the communication must be tested and needs to be in accordance with the interface documentation definition: communication channels, keep alive messages, hearth beat message, request message to weight item and reply message with the weight result.

Practical Example

As hardware functionality FSC sends a 24Vdc with the dimensions of the item (as if it was a photocell sensor) when the front of the item reaches 300 mm from the beginning of the scale conveyor. The request message is sent 50 mm after the beginning of the hardware trigger.

Regarding the message structure, bellow it is shown a practical example of messages structures exchanged between FSC and the weighing scale controller.

FSC to Scale → read request

<stx>id1|ppppp|<checksum><etx><cr>

<stx>10|00023|<checksum><etx><cr>

Scale to FSC → read result

<stx>id2|ppppp|t <weight>|<unit>|<checksum><etx><cr>

<stx>12|00023|6 000024500|g|<checksum><etx><cr>

Field	Definition
id1	Request message identifier (10)
id2	Result message identifier (12)
ppppp	Item unique identification code. Exemple: 00023
t	Scanner data state: No read (5), Good read(6)
<weight>	9 numeric characters with item weight. Example: 000024500
<unit>	Unit. Example: grams (g)

Table 5-4 Message structures definitions.

<u>Weighing scale read rate performance tests</u>

Regarding the testing, it will happen in three phases: weighing scale read rate performance tests and exceptional test scenarios tests. The tests need to be performed with the smallest item with minimum weight and biggest item possible with maximum weight.

During the tests it is important to verify if the weighing scale is being affected by external vibration caused by other conveyors. This happens mostly when the scale is installed directly on a platform.

<u>General read rate verification</u>

T1. Place manually an item with average size and valid known weight regarding the system characteristics on the upstream section of the weighing scale (conveyor 1 as indicated on figure 5-30), when the system is running in automatic. Repeat the test ten times with the same item.

R1. The weighing scale controller should return 100% correct reads to FSC on the downstream section (conveyor 2 as indicated on figure 5-30). The weight results should be within the specified weight error margins and comparable when placing the same item multiple times.

Theory Input:

Commonly the used weighing scale type has on its working principle a stabilization time. When the scale detects that the item is fully on the scale and its weight is stable for certain period of time the result is measured and returned on the downstream section to FSC.

For very large items, the stabilization time can be short, so it is important to test the weighing scale interface with the largest item possible for the system.

T2. Use the smallest and lightest item type that the weighing scale should weight accurately. The weight of the item should be known prior to the test and the test case 'T1' should be repeated with this new item.

R2. The expected result should be 100% read rate within the specified weight error margins.

T3: Use the biggest and heaviest item type that the weighing scale should weight accurately. The weight of the item should be known prior to the test and the test case 'T1' should be repeated with this new item.

R3. The expected result should be 100% read rate within the specified weight error margins.

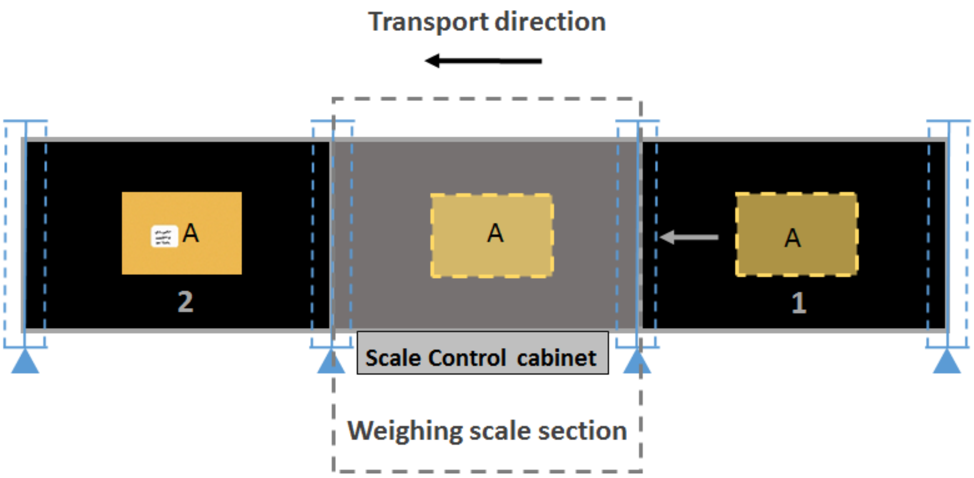


Figure 5-30 Weighing scale general read rate performance tests.

Advanced read rate tests

T4: Place manually an item with average size and valid known weight regarding the system characteristics on the upstream section of the weighing scale, when the weighing scale and the upstream conveyors are in dieback.

R4. The weighing scale controller should return 100% correct reads to FSC on the downstream section. The weight results should be within the specified weight error margins.

- Theory Input:

  Some weighing scales can have a time delay after its conveyor starts running, before it can start weighing items or can even be related with the minimum weighing speed. If there are problems validating this test case, on FSC can be programmed a cascade time or distance delay on the upstream conveyor for dieback scenarios. This will allow the weighing scale to run a small period of time before the next item arrives. However the value should as low as possible, otherwise the system will lose capacity.

T5: Place manually an item with average size and valid known weight regarding the system characteristics on the upstream section of the weighing scale, when the weighing scale and the upstream conveyors are running in automatic. At the moment that the item is on the weighing scale a dieback scenario should be forced leaving the item stopped on the scale. After the dieback being resolved the item should continue its normal transportation.

R5. The weighing scale controller should return 100% correct reads to FSC on the downstream section. The weight results should be within the specified weight error margins.

T6: Place manually three items with average size and valid known weight regarding the system characteristics on the upstream section of the weighing scale, when the weighing scale and the upstream conveyors are running in automatic. At the moment that the second item is passing on the weighing scale, it should be removed manually.

R6. The weighing scale controller should return 100% correct reads to FSC regarding the first and third item on the downstream section. The weight results should be within the specified weight error margins.

- Theory Input:

  During normal operation it can happen that the sensor updates get false triggers due to small pieces of lost papers or parts that can fall from items. This “fake” items can cause some disturbance on item tracking, but the weight of the real items should never be mixed up or disturbed due to this exceptional situations. In the worst case the weighing scale should return an error value that certain item could not be weighed.

T7: Place manually two items with average size and valid known weight regarding the system characteristics on the upstream section of the weighing scale, when the weighing scale and the upstream conveyors are running in automatic. The items should be placed as close as the scanner supplies claims the scale can read. However the gap between items should never the length of the scale conveyor otherwise there will be a big lost in capacity.

R7. The weighing scale controller should return 100% correct reads to FSC regarding the two items on the downstream section. The weight results should be within the specified weight error margins.

- <u>Theory Input:</u>

  The weighing scales should cope with two items at the same item on the scale. This means that when the first item enters the scale, the scale controller should have enough time to weigh the item and store its value before the second item arrives. Regarding the second item, when the first item leaves the scale, the scale controller should have enough time to weigh it and return the result to FSC. Three items on the weighing scale at the same time is not allowed, the gap control should be programmed in a way to avoid this cases and still provide the maximum capacity.

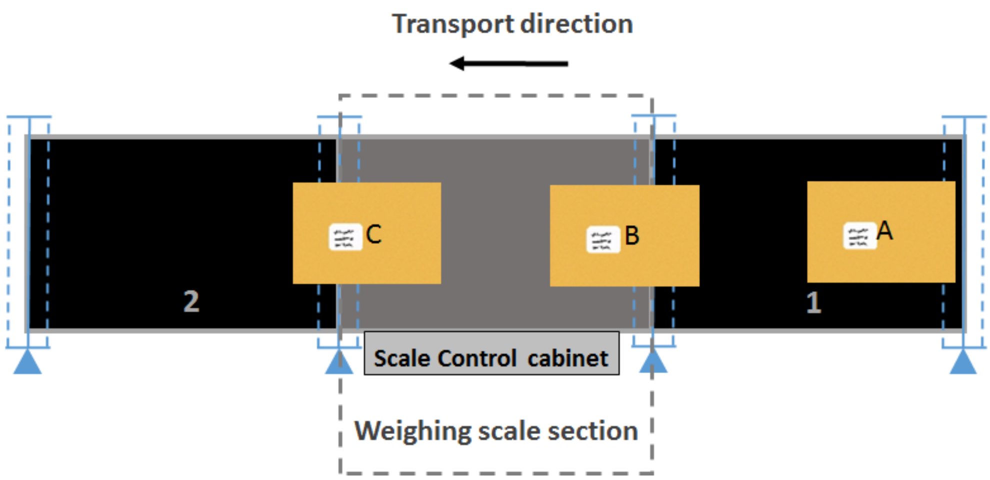


Figure 5-31 Weighing scale weighing two items.

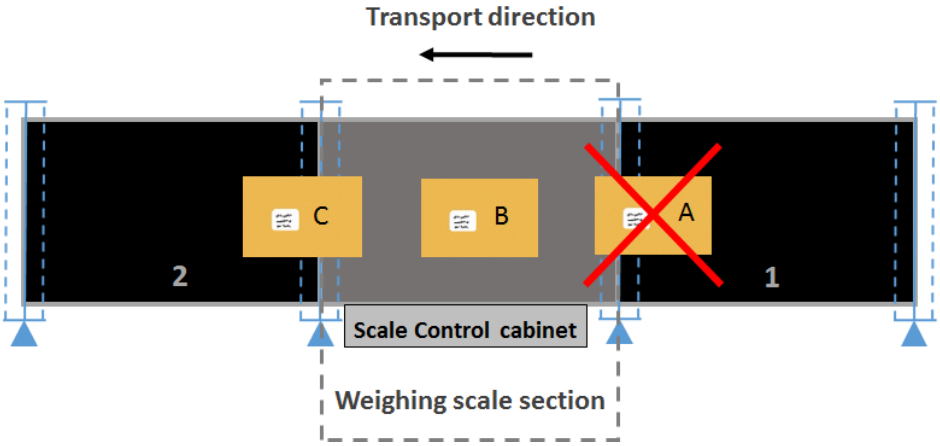


Figure 5-32 Weighing Scale cannot weigh three items at the same time.

<u>Exceptional error scenarios</u>

All error scenarios mentioned on the interface specification of the weighing scale, should be tested, this includes:

- Error codes for maximum allowed weight surpassed and minimum weight not reached;
- Error codes for weighing scale malfunctioning. FSC should receive a bit or a heartbeat message that the scale working accordingly.

5.2.3.3.13. <u>Flow Controller to Flow Controller interface</u>

This subchapter explains how to commission the interface between two flow controllers from different subsystems and networks, when handing over an item from system A to system B.

As first step it is necessary to commission the hardware interface according to the specified functionalities. The type of hardware interface is mainly chosen according to the network used in both subsystems. Generally is used a field bus coupler for this purpose where inputs and outputs are exchanged between both controllers.

- <u>Theory Input:</u>

  A field bus coupler separates two networks, even if both subsystems have the same network technology, such as PROFINET. If a node on network A has the same IP as a device on network B, on the other side of the coupler, it will not have any interference since the field bus coupler has the single purpose of exchanging I/O and no extra communication protocol is possible. In terms of controls programing it functions for both controllers as an I/O module. In the range of the field bus couplers there are several hardware types, the difference is mainly justified due to the network technology used on each system. Is commonly used as hardware interfaces for FSC to PLC or other FSC interface, the PROFINET/ PROFINET coupler (PN/PN coupler) and the PROFINET/ PROFIBUS-DP coupler (PN/DP coupler).

In order to couple both subsystems is necessary to have the I/O range in line on both controllers. This means if FSC has 10 bytes inputs and 15 bytes outputs, PLC should have 15 bytes inputs and 10 bytes outputs.

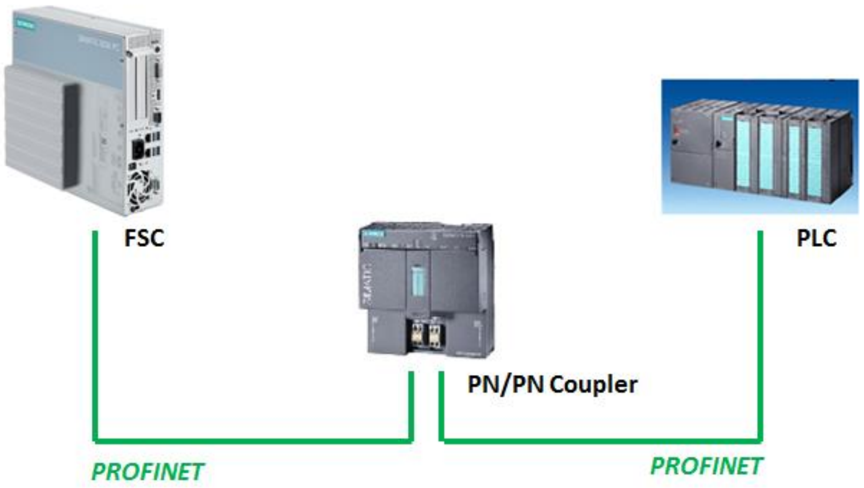


Figure 5-33 PN/PN coupler hardware interface representation.

Regarding programming the interface functionalities between two flow controllers, there are several methods and each system requirements leads to a tailor made interface. However, the interface types can be divided in two major groups: Single IO exchange for a single functionality and multiple I/O sequence exchange with synchronization for a single functionality.

5.2.3.4. Single I/O exchange functionality

This type of interface is used when one controller is looking to a single bit sent from other controller in order to trigger an action or ask permission for an action. For example, a gravity roller chute controlled by a PLC, all the programed logic for its availability and item processing logic is on PLC scope. However, FSC interfaces with PLC via a single bit regarding the chute availability, so it knows when it can sort an item. On another hand, if the PLC has a driven roller section in the same chute, FSC can send a wake up single bit signal so that PLC can start the roller section before the item arrives.

Regarding functionality test, it is important to verify that every single bit is programmed as specified. The time that the programed event takes to take action is also very important. For example, a chute is set to unavailable after a specified photocell sensor gets blocked for certain period of time, and it becomes back available after certain period of time that is unblocked. To get the best performance out of this type of interface it is advised that PLC which is fully in control of the chute to be owner of the availability times, FSC should just sort or stop sorting as soon as the signal exchange, with minimum time delay possible.

5.2.3.5. I/O exchange sequence functionality

This type of interface is used when transferring one item from one conveyor to another conveyor controlled by a different controller. The interface can happen in both directions, from FSC to PLC or from PLC to FSC. Compared to single I/O exchange interface, is more complex since requires more than one I/O to transfer an item and the synchronization between both controllers is critical.

As a pre-requirement before implementing this interface both controllers, sender and receiver need to have an accurate item tracking set in place before integration.

The interface documentation should be in the lead for the correct I/O addresses, bit sequences or words, and timing between both controllers.

Bellow it is described the general signals necessary to transfer items from the sender conveyor to the receiver conveyor:

Signals set by the sender:

- Request-To-Send (RTS) – The sender has an item ready for sending to the receiver at his announce position. When during the transfer an error occurs at the sender, the signal will temporary drop;

- Reset E-Saving (RES) – The sender send this signal to wake up the downstream section of the receiver;

- Transfer-In-Progress (TIP) – The sender indicates that the item is being transferred. The conveyors are coupled;

- Item-Handover (IHO) - The sender reports that the item is at the handover position (end of the sender controlled belt) via the IHO signal. This signal id used to increase the accuracy of tracking data handover.

Signals set by the receiver:

- Ready to Receive (RTR) – The receiver is ready to receive the next item. As precondition for this signal to be "high" the conveyor must be running. The signal becomes low when the receiver conveyor section is not able to receive any more items (example: error, dieback, or gap control). When during the transfer an error occurs at the receiver, the signal will temporary drop.

As additional signals is also used a life-sign bit per each interfaced line in order to make sure that all signal times are correct, especially for the cases that the interface happens with PLC which can be affected by the downside of its program cycle time. The life-sign bits serve as a health check for the conveyor line interfaced.

Extra notes:

- The RES is optional since the receiver conveyor can wake up also via the RTS, but sometimes it can cause an unnecessary start-stop behaviour and can have a negative impact on high capacity conveyor lines;
- When handing over an item from the sender to the receiver it is also possible to send data attached to it (example: barcode, entrance line, default destination). For these cases, a specified data length or word needs to be defined to be sent at the same time of the IHO signal and it needs to include a sequence number word which increases sequentially from 1 to 256 so that he receiver knows that each item is a new item.

Regarding the testing, the following diagram on figure 5-34 represents how the general signal sequence should happen during normal item flow:

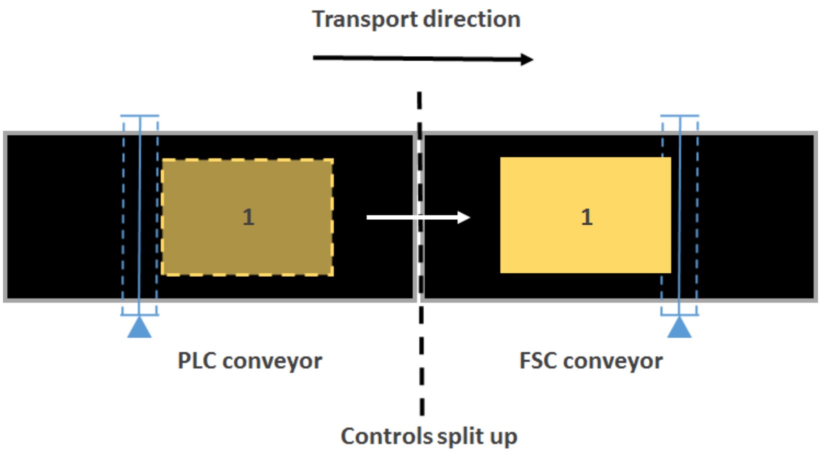
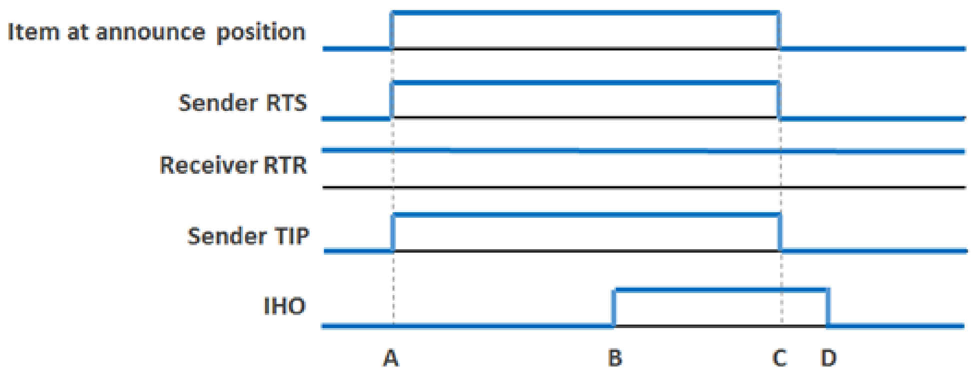


Figure 5-34 Controls split up.



Caption:

A – Item “head” arrives at sender announce position and sets RTR and since the receiver is on RTR the sender starts immediately with TIP;

B – Item “head” arrives at the handover or controls split up position and the sender raises IHO

C – The item leaves the scope of the sender;

D – Item “tail” reaches the IHO position and the handover is finalized.

Figure 5-35 RTS, RTR and IHO time diagram during normal flow.

5.2.3.5.1. <u>Destination server (DS) interfacing</u>

The interface commissioning of the destination server (DS) is divided in:

- Hardware interface;
- Interface messages;
- Testing.

The hardware interface consists in the physical connection via Ethernet cable CAT-6 or higher and configuring the IP address the destination host server and FSC in the same IP range as it is specified. When the cable connection is connected, communication channels, keep alive messages and hearth beat messages are programed accordingly.

After the communication being stablished between FSC and the DS, specified messages need to be programmed on both controllers, as sender and receiver.

The most common messages are:

- <u>Destination request</u> – Is the message that FSC requests a destination for an item which may contain certain data (barcode, weight, volume, etc);
- <u>Destination reply</u> – DS replies to FSC with one or more valid destinations;
- <u>Sort report</u> – FSC sends a report message when an item left the sorter in case being sorted or by being lost in tracking;
- <u>Failed sort report</u> – FSC sends a report message when an item was not possible to be sorted with the failed reason(s).
- <u>Recirculation report</u> – FSC sends a report message when and item passes certain position on the sorter counting the number of recirculation of the item and the item status (if is blocked, current destination, barcode, etc).

It is also common to have other messages beyond the previously mentioned, such as, item announce messages at certain conveyor section position.

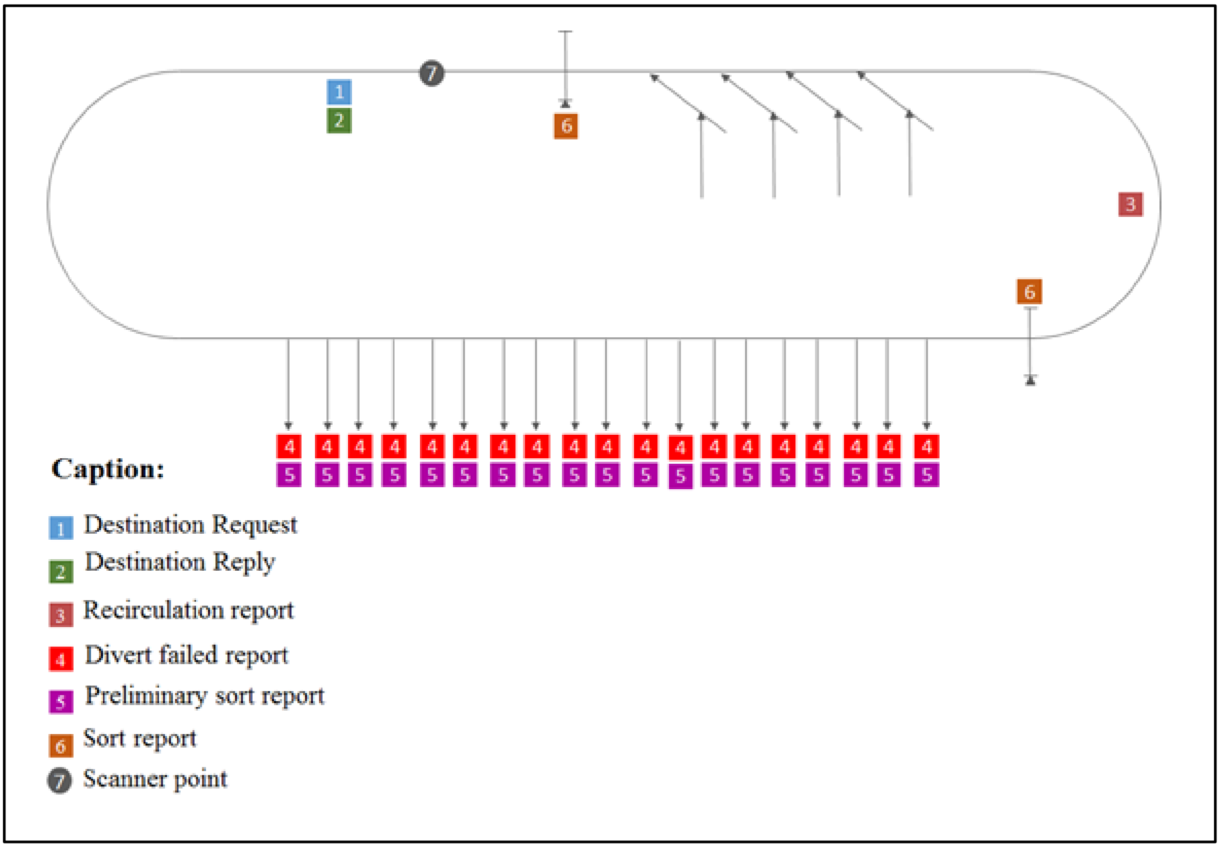


Figura 5-36 FSC and DS communication points overview.

All messages mentioned are programmed according to each system definitions and requirements. Each system can have different message fields (barcode, volume, weight, etc) which DS requires to set a valid destination.

Regarding the testing, it is all the following validations are completed:

- Verification of all message fields structures, checking if both controllers (FSC and DS) can understand each other in all the messages exchanged;
- Sorting to all destinations with the DS, making sure that there is no mismatch in the destination assignment between FSC and DS;
- Verification that the alternative destinations are working and with the expected functionality and sequence;
- Verification the time delay that the DS takes to reply to FSC. It is important to know DS response time related the *destination request* messages and if it is stable. In general the *destination request* message should not take more than 200ms to be sent

after a *destination request.* If a bigger delay happens it should be expected and specified in the interface documentation.

Practical Example

Regarding the message structure, bellow it is shown a practical example of messages structures exchanged between FSC and the Destination server.

FSC to DS → Destination request

<stx>id1|ppppp|aa..aa| <scale raw data> |<barcode raw data>|<volume raw data>| ee.ee|es| yy.yy1|yy.yy2|yy.yy3 |FW| <checksum><etx><cr>

<stx>20|00023|00190100203020304908121|6 0100020004500009|6 0020PBOX828006800100|6 0100020004500009| 0050.21.01.PEC31|1|03|10|23 |534| <checksum><etx><cr>

DS to FSC → Destination reply

<stx>id2|ppppp|ooo|v|<checksum><etx><cr>

<stx>20|00023|324|1|<checksum><etx><cr>

FSC to DS → Sort report

<stx>id1|ppppp|aa..aa|ooo|v|ods|ccc| <checksum><etx><cr>

<stx>21|00023|00190100203020304908121|324|1|1|324| <checksum><etx><cr>

Field	Definition
id1	Request message identifier (20)
id2	Reply message identifier (21)
ppppp	Item unique identification code. Exemple: 00023
aa..aa	Unique ID used for legal for trade certification, with 23 characters. Example: 00190100203020304908121
<scale raw data>	Weighing scale raw data. Example 6 0100020004500009
<barcode raw data>	Barcode scanner raw data. Example: 6 0020PBOX828006800100
<volume raw data>	Volume scanner raw data. Example: 6 0100020004500009

ee.ee	Entrance point, first position where item was detected in the system. Example: 0050.21.01.PEC31
es	Entrance state: No entrance state (0); New Item (1); Unexpected (2)
yy.yy1	Weighing scale ID, Example: 03
yy.yy2	Barcode scanner ID: 10
yy.yy3	Volume scanner ID: 23
FW	Carrier number which item is placed. Example: 534
ooo	Original destination. Example: 324
v	Destination translate state set. Translation state ok (1); Illegal label (2); No read label (3); No destination found (4)
ods	Original destination state. Sorted (1), Destination not reached (2), destination not available (3), failed to sort (4).
ccc	Actual destination. Example: 324

Table 5-5 Message structures definitions.

5.2.4. Testing and validation:

The final testing and fine tuning is one of the last project phases. It is important to review once more the most important functionalities of the *Cross belt sorter* and requirements:

- <u>Safety</u> – All emergency push buttons need to stop the related safety zones and the building fire alarm signal needs to be double checked;
- <u>System capacity</u> – The single induct and group of inducts capacity needs to be tested. This requires the preparation of the correct item dimensions for the test and trained system operators assistance in order to place the items with the correct positioning.

  ➢ <u>Theory Input:</u>

  When the single induct capacity is too high on a merge zone which contains four or more inducts, in some cases it is better to lower the single induct capacity so that the most upstream inducts related to the merge don't consume most of the available induct windows and the capacity is more proportionally distributed between all inducts;

- Sorting real items – When placing real items on the system is possible to fine tune the items behaviour close to the operation environment that it will be exposed. With real items it is possible to find eventual electromechanical irregularities,
- System performance measurements – The performance measurements should be done when the system is operating on relatively high capacity. The signs that can be taken into account and analysed are communication faults between FSC and different nodes (high number of communication timeouts and faults), generally the CPU load on the machine should be working stable below the 80%;
- Special system functionalities – As practical example, blocking items over dimensions or over weight before entering the system.

5.2.5. Customer validation:

At the final stages of the project customer will review all the specified requirements on the system which include most of the test and validation steps mentioned earlier, such as system capacity, system performance (inducting and sorting), system safety and the special requirements functionalities defined for the project. During the customer validation he/ she approves also the mechanical installation and electrical works as well, not only the system controls functionalities, components of the system need to be approved.

5.2.6. Support:

Once the project is delivered to the customer, the system starts its normal operations. In order to ensure the system is operating as specified during live operation a customer support period is given to the customer on site, between two to four weeks. This period serve also as customer training, to know how to deal with system exception errors and increase their confidence in operating a complex automated material handling system.

5.2.7. Closing project:

Finalizing the project, backups from controller nodes are done and as-build documentation regarding project changes on site. Customer has full ownership of the system and all further customer requests are directly managed by Vanderlande service department, since project was closed.

6. CONCLUSION

As conclusion the *Cross belt technology* is mainly used in the market areas of warehousing, parcel, e-commerce and retail. It has considerable advantages comparable to other sorting solutions, such as, being able to sort a wide range of products (envelops, clothing, cartoons, etc.) with high capacity, it has a high flexible layout with multiple combinations possible, making better use of space. Other considerable advantages are the low operation noise and lower power consumption for the solutions that use Linear Synchronous motors to drive the sorter.

Regarding the *Cross belt sorter* working principle, it has the main focus of sorting accurately a large item volume. The sorting process happens in different stages, depending also in the *Cross belt sorter system* design specifications, but in general items enter the system via the induction lines, being inducted into the sorter afterwards. Thereafter each item is scanned for barcode label and its volume measured by scanner systems. When the scanning are obtained the *Loop sorter* main controller requests a destination to the Destination Host server, by sending all item data collected, (weight, barcode, volume, etc.) and the destination is sent back to the *Loop sorter* controller to conclude the sorting process. The process is finalized by confirmation of sort reports.

Relatively to the technology, the *Cross belt systems* are composed by different technologies and subsystems in order to execute its main sorting function. Beyond the *Loop sorter*, this system is also generally composed by a plurality of conveyor belts and rollers, barcode scanners, volume scanners, motion weighing scales and other subsystems. Regarding control components, there is a main controller which is usually an industrial PC or a PLC and communicates with the different system slaves. The slaves can be simple I/O modules to control motors, actuators and sensors or advanced embedded systems that are used for instance to control light grid barriers. Regarding communication protocols, there is a main network (example: PROFINET) that enables the communication between the main controller and the different system slaves, including communication *gateways* that have the function of converting the main communication protocol to a secondary network, such as the AS-Interface.

Summing my experience with the *Cross belt technology* the current market treads reveal that there is higher need for more smart, efficient and sustainable solutions that can process products with high capacity. Consequently, the *Cross belt systems* will need to follow the same market treads and be able to develop more advanced sorting functionalities and more flexible interfaces.

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32336

UNIVERSIDADE DO ALGARVE

MARIA CARLOS DA ASSUNÇÃO ALHO FERREIRA, Diretora dos Serviços Académicos da Universidade do Algarve, certifica, em face dos respetivos registos existentes nesta Universidade, que: --

MÁRIO JOÃO SILVA BENEVIDES, natural de Ponta Delgada, filho de João Carlos de Medeiros Benevides e de Leomena Maria de Jesus Silva Benevides, portador do Cartão de Cidadão n.º 13262429--.

Concluiu no dia 23 de setembro de 2011, no Instituto Superior de Engenharia desta Universidade, o 1.º ciclo de estudos do curso de Licenciatura em Engenharia Elétrica e Eletrónica, pelo que lhe é conferido o grau de Licenciado em Engenharia Elétrica e Eletrónica - Ramo de Sistemas de Energia e Controlo, com a informação final de onze (11) valores, qualificação de Suficiente --.

O interessado não requereu o respetivo diploma---.

A presente certidão vai autenticada com o selo branco desta Universidade-------------------.

Faro, 17 de outubro de 2011.

A Diretora dos Serviços

(Maria Carlos Ferreira)

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UNIVERSIDADE DO ALGARVE

UNIVERSIDADE DO ALGARVE SERVIÇOS ACADÉMICOS

CERTIFICATE OF ACADEMIC ACHIEVEMENT

Student	: **32336 - MÁRIO JOÃO SILVA BENEVIDES**
Father's Name	: JOÃO CARLOS DE MEDEIROS BENEVIDES
Mother's Name	: LEOMENA MARIA DE JESUS SILVA BENEVIDES
Date of Birth	: 16-07-1987
Identity Card No	: 13262429
Course	: 1477 - ELECTRICAL AND ELECTRONICS ENGINEERING - SPECIALIZATION IN ENERGY AND CONTROL SYSTEMS (2nd cycle)
Scientific Area	: ELECTRICAL ENGINEERING
Degree	: *Mestrado* (Master's)

Subject	Academic Year	Mark 1	Mark in Words	ECTS	NB
ELECTRICAL ENERGY SYSTEMS	2011-12	15	Fifteen	10	---
LINEAR SYSTEMS	2011-12	12	Twelve	10	---
PROCESSING OF ELECTRIC POWER TRANSMISSION	2011-12	16	Sixteen	10	---
PROTECTION AND CONTROL OF ELECTRICAL ENERGY NETWORKS	2011-12	14	Fourteen	10	---
RENEWABLE ENERGIES AND SUSTAINABLE MOBILITY	2011-12	14	Fourteen	10	---
INDUSTRIAL INSTRUMENTATION	2011-12	14	Fourteen	10	---
ENERGY MANAGEMENT AND SUSTAINABLE DEVELOPMENT IN EUROPEAN UNION	2012-13	15	Fifteen	10	---
RENEWABLE ENERGIES	2012-13	17	Seventeen	3	Uci
INTELECTUAL PROPERTY RIGHTS AND BUSINESS PLANNING	2012-13	19	Nineteen	6	Uci

In light of the relevant records, I hereby certify that the above-named student passed in the subjects listed with the marks shown and has therefore qualified in the curricular part of the Mestrado (Master's) course in Electrical and Electronic Engineering, with specialisation in Energy and Control Systems, corresponding to 70 ECTS, having thereby earned a Specialization Diploma on the 15th of March 2013, with a final overall mark of fourteen (14), which is classed as Good.

This certificate, comprising 1 sheet, is authenticated with the embossed seal of this University.

p) Faro, this 12th day of April 2016.
The Director of Academic Services

Conceição Oliveira

(Maria Carlos Ferreira)

Conceição Oliveira
Chefe de Divisão

Certificate Fees: 53.25 €

Checked by: Sílvia Dimas

SÍLVIA DIMAS
ASS. TÉCNICA

NB:
(Cr) - Pass obtained by means of credit from a previous course
(Uci) - Outside option
(M) - Reassessment

---

[1] Marks at Portuguese universities are awarded out of a possible total of twenty. (Translator's Note)

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V GM
C HECKLIST
A ANNEMERS

Diploma

Basic Elements of Safety VCA
Basisveiligheid VCA

Name/naam:	M.J. Silva Benevides
Date of birth/geboortedatum:	16-07-1987
Place of birth/geboorteplaats:	Ponta Delgada Ilha De Sao Miguel
Date of issuance/datum uitgifte:	23-02-2015
Place of issuance/plaats van uitgifte	Zwijndrecht

On behalf of the examination center
Namens het Examencentrum VCA

F.P. Hiddink

Graduate Holder
Gediplomeerde

M.J. Silva Benevides

The diploma is valid up to 10 years after date of issuance.
Het diploma is geldig tot 10 jaar na de datum van uitgifte.

Koninklijke PBNA

377381.00061546

This diploma is registered in the Dutch Central Diploma Register VCA.
Dit diploma is geregistreerd in het Nederlands Centraal Diploma Register VCA.

The examination was conducted in the following language:
Het examen is afgenomen in de volgende taal: English/Engels

The holder of this diploma has passed the examination which was composed by the VCA Examenbank on the basis of the attainment targets and testing targets as specified by the CCVD-VCA.
De houder van dit diploma heeft met goed gevolg het examen afgelegd dat is samengesteld door de VCA Examenbank aan de hand van de eind- en toetstermen die zijn vastgesteld door het CCVD-VCA.

The Stichting Examenkamer (Dutch Foundation) supervises the VCA exams and examinations.
De VCA examens zijn afgenomen onder toezicht van de Stichting Examenkamer.

Volgnummer:0001245438

ES ELEKTRO CURSUS CERTIFICAAT

We herewith declare that,

M. Silva Benevides

completed the cours

*S7-PROFINET-E: S7-300/400 Ethernet en Profinet

held on

04 till 06-feb-2015 at the location: Veghel

successfully.

Subjects:

Systeemoverzicht INDUSTRIAL ETHERNET / PROFINET
Opbouw van een ETHERNET / PROFINET netwerk
PROFINET en ETHERNET communicatie processoren

- S7-300/400 (kaarten) met ETHERNET mogelijkheden
- S7-300 (kaarten) met PROFINET IO mogelijkheden
- PC kaarten met SIMATIC NET en OPC software

ETHERNET / PROFINET netwerk componenten

- Zowel optische als elektrische, bekabeling, switches, routers, wireless etc.

Projecteren van een netwerk met STEP7 software:

- ETHERNET netwerk parameters
- Additionele PROFINET parameters naast ETHERNET parameters
- CP kaarten in de PC en PLC
- PROFINET IO Devices
- Opzetten van ETHERNET verbindingen tussen deelnemers
- Opzetten van PROFINET IO verbindingen tussen deelnemers
- Opzetten van een draadloze verbinding voor ETHERNET en PROFINET

Inbedrijfnemen van een ETHERNET en/of PROFINET netwerk
Storingzoeken in een ETHERNET / PROFINET netwerk via storings-LED's, verschillende diagnosemiddelen van STEP7, via NCM en via het gebruikersprogramma.

Course leader

Herman Vermerris

ES Elektro Cursus
Certificaat

itsme
INDUSTRIALAUTOMATION

ISO 9001 BUREAU VERITAS Certification

cedeo*erkend Bedrijfsopleidingen Open

ES ELEKTRO CURSUS CERTIFICAAT

We herewith declare that,

M. Silva Benevides

completed the cours

**S7-SAFETY-E: S7-300/400 Safety*

held on

27 till 28-jan-2015 at the location: Veghel

successfully.

Subjects:

- *Systeemoverzicht SIMATIC S7 Distributed Safety.*
- *Opbouw van een Safety systeem.*
- *Opbouw van een Safety programma.*
- *Safety toepassen via PROFIBUS en PROFINET*
- *Safety Hardware configureren*
- *Een FailSafe besturingen in gebruik nemen*
- *Diagnosticeren van FailSafe besturingen*
- *Praktijkoefeningen.*

Course leader

Jarik Gelderblom

ES Elektro Cursus Certificaat

itsme INDUSTRIALAUTOMATION

ISO 9001 BUREAU VERITAS Certification

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ES ELEKTRO CURSUS CERTIFICAAT

We herewith declare that,

M. Silva Benevides

completed the cours

*S7-SYSTEM-E: S7-300/400 System course English

held on

21 till 23-jan-2015 at the location: Veghel

successfully.

Subjects:

SIMATIC S7 System Overview.
Operation of the SIMATIC S7 PLC.
Structure of a program.
STEP7 BASIC software package:

- global settings (authentication, language and PG / PC interface);
- dealing with projects (create, modify, download and upload);
- Hardware Configuration and Symbolic Names;
- working online;
- Clearing the PLC / programming memory cards;
- documentation options (comment);
- reference data (cross reference list, program structure, etc.);
- testing the program (debug / status / control);
- setting the CPU clock;
- Changing the CPU operating mode;
- scan cycle times and memory occupancy.

Addressing of the I/O cards;
Troubleshooting hardware (hardware diagnostics with STEP7);
Troubleshooting software (via CPU diagnostic buffer and Stacks);
Making a STEP7 project:

- Create hardware configuration;
- symbolism table;
- edit (data) blocks (use STEP7 programming-editor).

Course leader

Herman Vermerris

ES Elektro Cursus
Certificaat

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